TIDAL LANDS

A STUDY OF SHORE PROBLEMS

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Plate XVII

PREFACE

The title of this handbook may be regarded as enshrining a solecism. The Standing Orders of Parliament, however, employ the same phrase, and in so doing perpetrate a paradox. They lay down rules regulating the deposit of plans, such plans being for "work which is to be situate on tidal lands within the ordinary spring tides". They then go on to direct that the documents so defined shall be duly lodged at the Office of the Harbour Department, Board of Trade, and marked "Tidal Waters". Ancient Roman writers betray a similar confusion of phrase. Describing the phenomenon of diurnal tides, a wonder migrants from the almost tideless waters of the Mediterranean could not fathom, they state that they were puzzled to say whether such territory was to be appropriately called land or water. Shakespeare's index of man's inconstancy was summed in the phrase, "one foot in sea, and one on shore".

This work is primarily concerned with those problems which underlie the maintenance of coastal and riparian lands, and, as a factor in such control, the extent to which horticulture may be enlisted in the cause of conservation. The original charter of the Institution of Civil Engineers defines the profession of the civil engineer as "the art of directing the great sources of power in Nature for the use and convenience of man". British engineers have perhaps been somewhat apt to disregard those transformations which are capable of being

brought about by vegetation. The chain of physical cause and effect is universal. Every dewdrop has its tidal ebb and flow, a subtle alchemy of force that links our earth with other worlds. *De minimis curat Natura.* Nature is conquered by obeying her, and man is but her puppet until he learns the lesson of obedience.

Whilst *Tidal Lands* is based primarily on the results of our own observations, experiments, and practice, spread over a long series of years, we have become indebted to many persons for information and help on particular points, for facilities of access to certain localities, and especially for the provision of many of the photographs here reproduced.

Among those of whose courtesy in these various ways we desire to make particular acknowledgment are: the late Dr. Sarah Baker; Dr. Winifred Brenchley; Miss Lilian Britten, of Port Elizabeth; Mr. G. O. Case; Mr. Linn Chilvers; Dr. L. Cockayne, F.R.S., of New Zealand; Mr. A. D. Cotton; Mrs. Cowles, of Chicago; Mr. E. P. Farrow; Sir Francis Fox; Dr. Somerville Hastings; Prof. Augustine Henry; Major T. G. Hill; Lord Ilchester; Mr. Alleyne Leechman, of British Guiana; Mr. J. H. Maiden, F.R.S., of the Botanic Gardens, Sydney; Prof. J. Massart, of the University of Brussels; Dr. C. H. Ostenfeld, of Copenhagen; Mr. William Rowan; Dr. E. J. Salisbury; Prof. William Somerville; Prof. C. Schroeter, of Zurich; Mr. R. V. Sherring; and Mr. R. Hansford Worth. By the courtesy of the Council of the Linnean Society we are able to republish from their Journal fig. 42 and Plate XV, 2. Fig. 3 has been reproduced from the diagram accompanying Mr. G. C. Churchward's letter published in the *Daily Mail*, 18th July, 1907.

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TIDAL LANDS

CHAPTER I

Tidal and Current Data

Tidal phenomena may be expressed as the resultant of the forces of mutual attraction between the earth and its attendant heavenly bodies. This attraction is directly proportional to their respective masses and inversely as the square of their respective distances. For practical purposes the movements of the sun and moon are the arbiters of tidal effect. The pull of the moon on the earth is rather more than double that of the sun, by reason of its comparative proximity.

Springs and Neaps.—The speed of revolution of the earth about its axis is such that the moon during each twenty-four hours occupies a period of about fifty minutes longer in reaching the same meridian. Setting aside minor perturbations of lunar movement, the result of this inequality of travel is that the times of high and low water lag some fifty minutes each day. This action results in what is described as the "priming" of the tide. The difference in height of the diurnal tides is due to the greater or less degree in which the attractions of the sun and moon are in opposition. When the moon is in its first and last quarters, or in quadrature, that is, when the positions of the sun and moon form a right angle with the earth-axis, the maximum retardation of tidal force results. This is the condition of *neap tides*. When the moon is at full and new the pull of sun and moon are in one and the resultant tidal lift is at its maximum. This is the condition of *spring tides*. Lunar full and change

It may be noted that half tide or mean tidal level is the mean between the four levels of mean high and low water at springs and neaps.

The Lords of the Admiralty annually publish *Tide Tables for Standard Ports in the United Kingdom and other Parts of the*

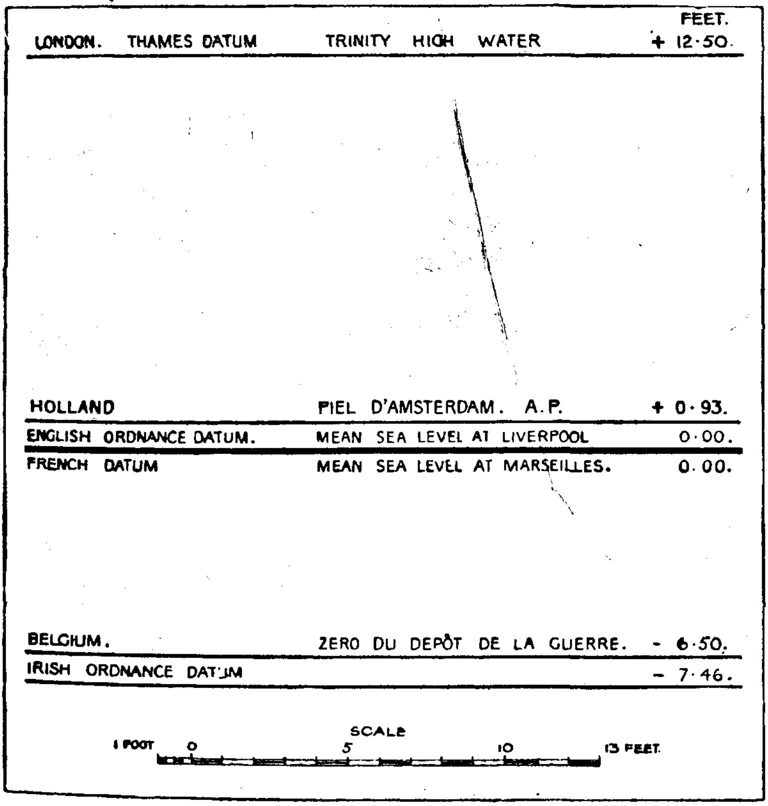


Fig. 1.—Foreign Tide Standards

World, and this work is the accepted official authority on the subject.

Port Establishment.—The high velocity of the great primary tidal wave is reduced when, in sailors' parlance, "it smells land". Thus in the North Sea it runs at 50 or 60 miles per hour. Entangled in local retardation, and subject to local dis-

turbance, tidal travel becomes a matter of observation rather than of calculation. If such observations are sufficiently long continued, an empirical basis for foretelling the periods of high and low water at a given port may be arrived at.

The interval at each port between the passage of the moon and the actual time of high water F. and C. is known as "the establishment" of that port. From this record a time-table of tides may be calculated, the connection between the periods of F. and C. following a defined sequence. The Admiralty charts supply this information at every port. Taking as an illustration the chart of the Rivers Orwell and Stour, the following phrase will be found:—

> "H. W. F. and C. at Harwich XI hours 56 minutes. Springs rise 12¾ feet, neaps 10½ feet, neaps range 7½ feet."

This phrase indicates the hour of high water at Harwich at the periods of new and full moon and the amounts of mean tidal lift.

The National Physical Laboratory has designed the India Office Tide Predicting Machine, which is a modification of Lord Kelvin's apparatus now in South Kensington Museum. It can be used for predicting the tides, and preparing tide-tables, for any year, for any port for which the constants requisite for setting the machine have been determined by observation.

The principle of the method may be briefly stated as follows: The tidal motion at any port can be analysed into a number of simple tides, i.e. simple harmonic oscillations of sea-level. The periods of these oscillations for the different component tides are determined from astronomical data, and are the same for all ports. The amplitudes and the phases of the several component tides are different for different ports. Twenty-four such components are included in the machine at the National Physical Laboratory. The amplitudes and phases of these twenty-four components are the constants above referred to, which it is necessary to know for any particular port in order to set the machine for predicting the tides.

These amplitudes and phases are determined from actual

tide-gauge records taken at the port in question. A single year's records are sufficient to give fairly good values of the constants, but for the more important ports it is desirable to analyse a longer period, and at some ports, e.g. Bombay, records are taken continuously. The height of mean sea-level above some datum is also determined from the analysis, and is employed in setting the machine.

The machine, when correctly set for any particular year, will run off a curve giving the height of sea-level above datum at any instant throughout the year. In preparing the usual tide-tables, the times and heights of the high and low waters are read off from this curve.

Wind Effects.—Winds cause much perturbation in the range of tidal lift. Long-continued gales heap up or depress water-levels many feet. In the North Sea the maximum effect is produced when an N.N.W. gale is blowing, accompanied by an S.W. gale in the English Channel. This conjunction of causes in 1905 produced a tide on the Suffolk coast 6 feet 3 inches above normal. At Liverpool tides abnormal, by reason of wind conditions, to the extent of 5 feet have been recorded. In 1876–7 three record tides in the Thames gorged the river to such a degree that large districts within the Metropolitan area were submerged. The maximum floods reached a level of 4 feet 3 inches above Trinity. The Thames Conservancy, who then controlled riparian problems in the lower river, as a consequence of these successive floods compelled the owners of all riverside premises to raise their fronts to a minimum height of 5 feet 6 inches above Trinity standard. It is roughly estimated that a heavy gale may increase the tidal height by one-twelfth of the normal calculated height at the point of observation. Gales are usually synchronous with low barometric pressure, and it is stated, on French official authority, that a variation of atmospheric pressure of one inch coincides with a + or – variation of about one-third of an inch per foot of tidal range.

In tropical localities wind action usually follows a well-defined cycle, the monsoons on the Asiatic coast, for instance, recurring with great precision. In temperate regions the seasonal disturbances are apt to be irregular.

Periods of Greatest Disturbance

English Channel, Irish Sea, and Atlantic Seaboards	November–February.
North Sea	January–April.
Cyclones in Indian Ocean	May–November.
Typhoons in China Sea	June–November.
Hurricanes in Caribbean Sea	July–October.
Hurricanes in South Seas	January–April.

The genesis of wave disturbance is wind action, and long-continued wind records are, therefore, of much value, but it

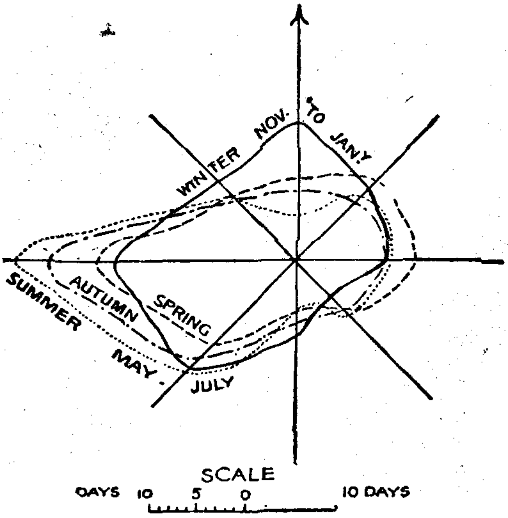


Fig. 2.—Diagram showing average Prevalence of Winds at Newhaven, 1847–83

must be borne in mind that they furnish little clue to the effect produced by periodic storms of exceptional severity. Diagrams of the average prevalence of winds, as shown in fig. 2, should be plotted, where the necessary data are obtainable. In a paper by Dr. Stanton, "On the Resistance of Plane Surfaces in a Uniform Current of Air",[1] much accurate observation in respect of wind velocities is collected.

Probably 90–100 miles an hour is the extreme limit of wind velocity. The pressure due to wind force is constantly fluctu-

[1] *Proc. Inst. C. E.*, Vol. CLVI, pp. 78–139.

ating and not a uniform and steady pressure. In the Report of the Committee on Wind Pressure on Railway Structures (1881), the following formula is adopted to indicate the relation between wind velocity and pressure:—

$$\frac{V^2}{100} = P,$$

V being miles per hour, P maximum pressure, the lowest value of V being 40 miles per hour. The results obtained by this formula between 40–80 miles per hour show a close approximation with experimental observation. Thus, with a wind having a maximum hourly run of 80 miles, the maximum pressure by formula is 64 lb. per square foot; according to experiment, 65.5 lb. per square foot.

Currents.—Current scour may be either the slave or the tyrant of the designer of harbour and river works. Dr. J. S. Owens, in a paper entitled "Experiments on the Transporting Power of Sea Currents",[1] evolved the following formula:—

If d = diameter of a flint stone in inches,
V = velocity required to move it in feet per second.

For ordinary pebbles $d = \frac{V^2}{2.2}$ approximately.

Fine sand $\frac{1}{80}$ to $\frac{1}{100}$ inch diameter begins to move under a current of 0.60 to 0.80 foot per second.

[1] *Journal of the Royal Geographical Society*, April, 1908, p. 417.

CHAPTER II

The Tidal Compartment of a River

The tidal compartment of a river may be defined as that portion of the stream which intervenes between the area of unimpeded tidal action and that in which there is a complete cessation or absence of tidal action. On the seaward side of the tidal compartment the accession and recession of the tides follow conditions similar to those of the contiguous open sea, unless these are modified by what may be termed accidental, or by local causes, such as shoals, races, or the gorging action of wind.

Rain and Rivers.—There is infinite variety in the *régime* of rivers, due to the contour and gradient of their bed and other physical conditions. The variations of rainfall on the earth's surface lie between nil and about 300 inches per year. On portions of the Essex coast the average is as low as 13 or 14 inches, and the Highlander's remark that the rainfall in his district was "aboot twelve fut" was under the mark in respect of the actual fall in some mountain districts of England. The extent to which percolation takes place varies relatively with the degree of impermeability of the subsoil, stiff clay or rock being water-arresting subsoils, whereas sand is penetrative in a high degree, until its pores become water-logged or choked with argillaceous matter. There is a wide range in the percentages of rainfall which reach their respective river systems. The average annual percentage of infiltration in England is about 42 per cent; the mean daily evaporation is 0.08 inch. These figures, however, have little value in relation to the problems of specific localities.

River Contours.—The force of the ebb current in a river

is the principal determining factor in its contour on plan. A sluggish stream of slight gradient will be found to follow a devious course, winding across the tract of country with many bends and pools. The degree of straightness in the course of a stream is an index of its velocity and of the tenacity of the soil through which it flows to resist the impact of water. Under normal conditions a river is perpetually subject to change of contour, due to land freshets or extreme tidal movements, which erode the banks or bed of its stream irregularly. Approximate stabilization of a river is usually brought about by the prolonged action of natural forces. The effect of such action is a mean sectional area in the river bed, which, being protected by the accretion of detrital matter, results in slopes of repose such that the banks are capable of resisting abnormal tidal impact. The curvatures in the course of a river are due to the force of gravitation acting on the inclined plane of the surface of the stream. The measure of the force is represented by the formula $g \times \sin i$, i being the inclination of the surface of the channel in degrees.

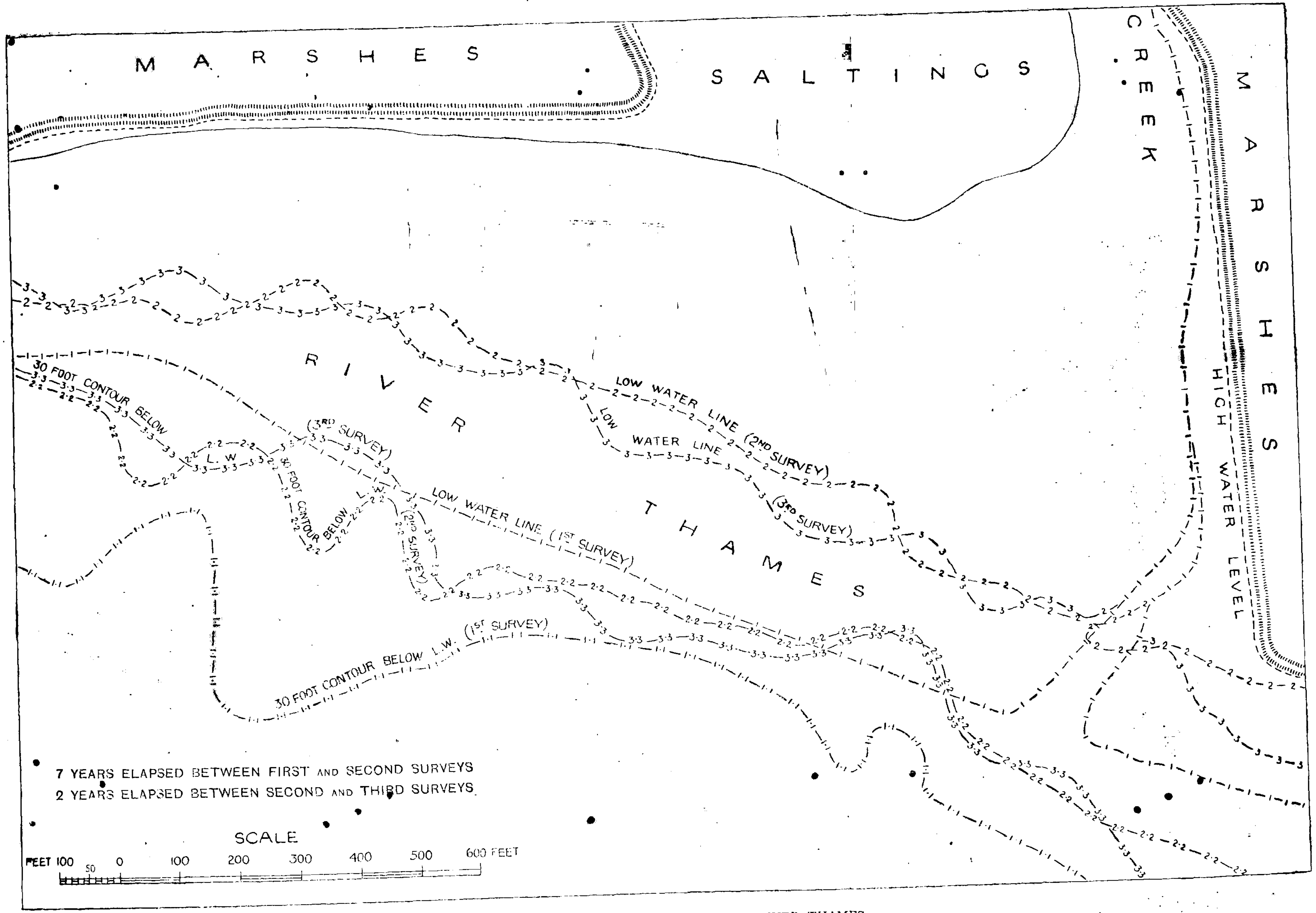
$$\text{Sin } i = \frac{h}{l} \text{ or } \frac{\text{height fallen}}{\text{length under observation}}.$$

Artificial Cuts.—From the fact that the natural course of a river is curvilinear may be deduced the inference that artificial rectilinear cuts should be avoided. Works for the amelioration of a deep river channel are, as a rule, more effective if, instead of endeavouring to cut a straight course, flat curves are employed. From London Bridge to the sea bends in the course of the Thames occur approximately every two miles. At Blackwall the river is about 1000 feet wide, and its curvature has a radius of about 1900 feet.

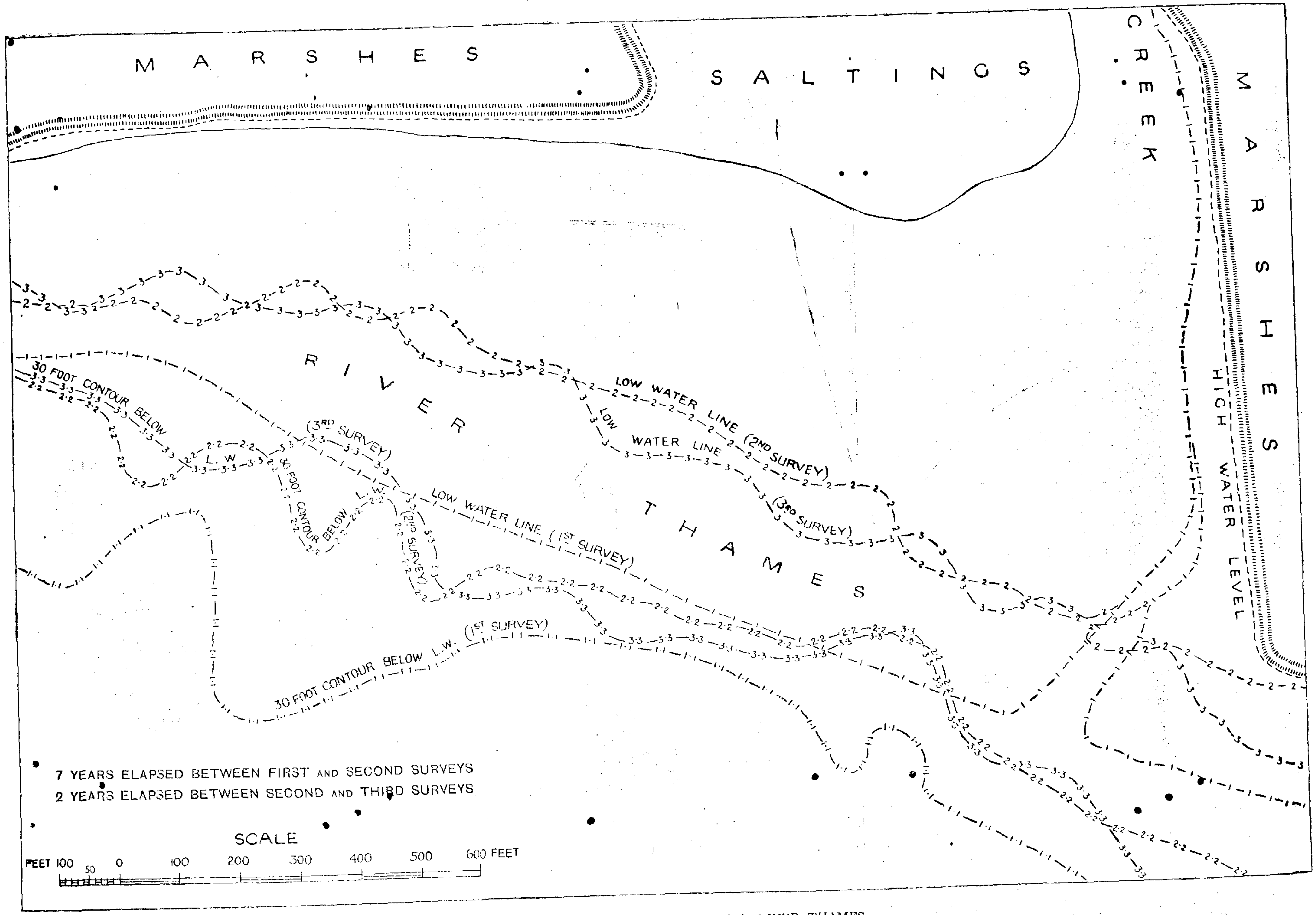
In the instances in which it has been attempted to abolish curvature in the channel of a river, the shoaling, which inevitably takes place, tends to become irregular and produce a tortuous waterway. The fairway of a river under such conditions oscillates, to the detriment of navigation. The art of remoulding the tidal compartment of a river presupposes float observations spread over a considerable period. From these

the measures necessary for humouring the stream, so as to produce continuity of current effect, may be evolved. S curves should be avoided, as at points of contrary flexure shoals are likely to result. The relation between the widths and depths of the channel and the distance apart of lengths of inflexion are the cardinal features to be studied. A channel should be widest at the summit of a curve and narrowed when curves change.

Dredging Disturbance in the Thames.—In the years 1906–9 the Thames Conservancy and the Port of London Authority carried out dredging operations in the Thames, whereby a channel 30 feet in depth at low water and 1000 feet in width was dredged from the Nore to the Albert Docks. Through the lower reaches of the Thames the river flows for many miles between artificial clay embankments, the land in rear of these averaging 9 or 10 feet below high-water level. The standard of the Port of London Authority for the height of these protective embankments is 5 feet 6 inches above Trinity high water, equivalent to 18 feet above O.D. Operations on a scale of magnitude such as those defined above necessarily produced local changes in the configuration of the river bed, owing to the varying strata underlying the channel. Plate I shows a typical fluctuation in underwater depths along one short length of the frontage of the Thames. This same frontage is now slowly becoming re-stabilized, but, as a result of the changes in contour, heavy defensive works have been rendered necessary to conserve the marsh embankments, which are the protection against flooding of many hundreds of acres of land. The river for untold ages has wandered in devious channels throughout its estuary, redistributing diluvium of a patchy character irregularly. During the Human Period the level of the river has probably been lowered not less than 60 feet, the stream having sawn its way down, leaving, tier above tier, terraces of sand and gravel. The flood-loam of ancient periods constitutes those vast areas of brick earth which now occur on both banks of the river. The regrouping of these deposits of "drift", or "high-level gravels", was probably the work of floods toward the termination of the Glacial Epochs.



PROGRESSIVE UNDERWATER EROSION, RIVER THAMES



PROGRESSIVE UNDERWATER EROSION, RIVER THAMES

In the lower reaches of the river, a deposit locally called "moor log" lies mostly about 4 feet below marsh level. It may be found about low-water level, when the outer toe of the river wall is scoured away or excavated. Moor log consists of small tree trunks, interspersed with brushwood, yew and willow forming a considerable proportion of the trees. These are strewn pell-mell horizontally, and are in diameter up to 14 or 16 inches. The stratum runs up to 10 feet in thickness, having often beneath it 12 to 15 inches of blue clay, and under this sand and gravel. At Deptford, it is stated to be 6 feet thick; in Woolwich Reach, 7 to 8 feet; and at Barking, 9 feet. It increases in thickness in passing down stream.

From its appearance the origin of the deposit may be surmised. A dense woodland, consisting of small trees and undergrowth, must have clothed the estuary of that which is now the Thames valley—then a tract of swamp and eyot. This tract of land and water probably slowly subsided, or became submerged by inundation, and a hurricane or successive tempests subsequently uprooted and strewed the trees in a confused medley. The existence of remains of the Irish elk above the moor log seems to indicate that its formation may have been coeval with palæolithic man.

Tidal Penetration.—The pressure of the diurnal tidal pulse penetrates wherever a vein of sand or pervious material exists abutting on a river, and this action sets up disintegration, and the consequent slipping of its banks. A notable instance of this action was seen in the settlement of St. Paul's Cathedral, which is founded on beds of sand overlying brick earth (fig. 3). The river toe of these beds for a short frontage opposite the cathedral having been cut away, the influx and efflux of the tide started a sort of sand-glass action, and the effect of this was a serious disturbance of the equilibrium of the structure, until leakage was stanched by detrital accretion.

Land Reclamation.—In the design of training works, one of the most important factors is to conserve the maximum *effective* tidal reserve capable of inducing scour on the ebb. Many examples exist of a short-sighted policy of land reclamation. The temptation to shut off areas of estuarial slob in

order to make land for agricultural or other purposes is sometimes insistent. This practice has been the fruitful source of river deterioration, in some cases amounting almost to extinction. From half-ebb onwards the scouring force of a stream is doing its best work. The greater the volume of effluent water impounded in reaches and by-channels, the stronger and longer will be such action. They constitute in effect a

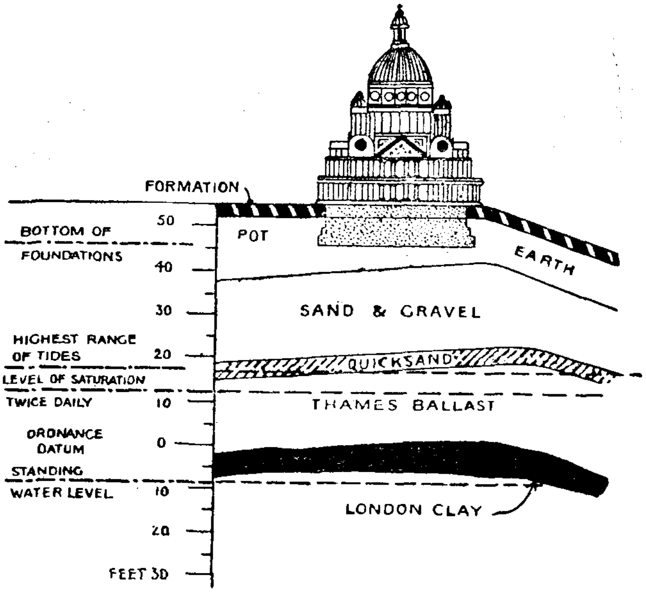


Fig. 3.—Diagram of Subsoils, St. Paul's Cathedral

natural reservoir, the water from which, under the force of gravitation as the tide falls, tends to throw into suspension and carry off superficial silt. The winning of tidal lands is, however, a perfectly legitimate and sound engineering undertaking, and, if carried out judiciously, innocuous so far as the maintenance of the river channel is concerned. Take the case of a river which zigzags, constantly shifting its route across alluvial flats. A big proportion of its waters will probably escape seawards uselessly, so far as the maintenance of the bed of the stream proper is concerned. Such waters wander across shoals, or fill depressions, and thus fail in the function

of scour. The severance of swampy lands where such action occurs may cause little or no diminution of effective effluent scour. When tidal lift is small, and its action consequently only capable of traversing a short range of the lower reaches of a river, dredging must pretty generally be relied upon to keep down artificially the accretion of deposits. A free movement of tidal waters up the course of a river should be jealously conserved, as this condition is normally one of the most important factors in securing the maintenance of deep water for navigation. Under these conditions, the work of the dredger is in the main to attack the bar at the exit of the river into the sea, and to cut away hard shoals in the course of the stream.

Entrance Channel.—If the section of the entrance channel is, owing to injudicious design, insufficient, the body of inflowing water is restricted, and the flood height of the river reduced, a condition tending to progressive and irregular shoaling. The goal to be attained is so to model the navigable channel that the maximum velocity and volume of tidal water may travel up the river bed to the extreme distance practicable. Captain Calver has laid it down as an axiom that the free access of tidal water is essential to a sea outlet and to keep down the tendency to bar formation, a result which the unaided flow of the stream cannot achieve. This generalization breaks down in the case of such rivers as the Amazon, from which a fresh-water stream is projected many miles into the Atlantic, the rise of tide being small. Broadly speaking, it is a sound rule to construct the entrance piers to a harbour parallel, projected an equal distance seawards, and bell-mouthed at the extremity. A study of the littoral conditions is essential to combat the accretion of drift. In many instances it is judicious to lay out entrance piers at such an angle that the prevailing columns of littoral drift striking the windward pier ricochet into deeper water. If entrance piers are not carried into deep water, and if a high and constantly recurring bar exists, it is permissible slightly to converge the entrance piers at their sea extremity, but so as to diminish the tidal flow as little as may be. If this is done judiciously, its effect may be to guide and augment the force of the ebb scour so as to check the formation of the most

of the Thames. In a recent discussion, at the Institution of Civil Engineers[1] the difficulty of arriving at a definition of the term "clay" and the ambiguity prevalent as to the angle of repose which may be safely assigned to it under varying physical conditions were emphasized.

A few years ago a suggestion was put forward for the construction of a barrage in the vicinity of Gravesend. Happily the proposal was vetoed by the shipping authorities of the port. Apart from the beneficial effect on the health conditions of London of the scavenging action of the tide, apart also from the cheap form of propulsion for barge traffic a tideway affords, the creation of an impediment to the free and unrestricted movement of tidal forces would almost certainly have resulted in a disastrous transformation of the estuary, setting up shoals, deep pools, and causing an erratic and tortuous channel. Every great waterway enshrines a compromise. Trade requirements, the amenities and hygiene of the towns upon its banks, the maintenance of a section such that accretion is kept under with a minimum of expense—these are the main factors in the problem. The function of the port authority of control is to hold the balance fairly between these often-conflicting elements. When a river runs abruptly into the sea with deep water close inshore, its regulation is a simpler problem than is the case when a wide and shifting estuary forms the connecting link between sea and river. In the latter case the primary consideration is usually to deepen artificially one outlet channel at the expense of subsidiary channels, so as to concentrate the action of effluent scour and force it to yield its best service.

River Training.—On rivers serving an inland port or ports the desiderata are:—

1. Sectional areas progressively lessening in passing upstream from the embouchure.

2. A river contour in which curves exist, alternately concave and convex, with straights tangential to the same. The contour should be laid out as regularly as possible, and the radii of curves should not exceed 3000 feet.

[1] "The Lateral Pressure and Resistance of Clay and the Supporting Power of Clay Foundations" (A. L. Bell), *Proc. Inst. C. E.*, Vol. CXCIX, pp. 233-336.

3. An entrance so planned and such absence of obstruction in the channel that the tide level at the port is at least as high as that at the entrance.

The questions of the velocity of the ebb current and the period of time of the tidal flow are, within limits, local in character, the great aim being to secure by regulated control such conditions that the shipping normally frequenting the river shall be navigated without let or hindrance, predetermined depths of waterway being automatically maintained. Granted an adequate backwater and maximum depths once secured, the ideal of a channel self-maintained by the scour of the ebb is the goal to be attained.

Dredging is the usual mechanical expedient by which waterways are improved or created. The advent of the modern suction dredger has transformed problems which baffled engineering science even thirty years ago. These machines are now constructed capable of lifting 10,000 tons of sand from a depth of 70 feet below low-water line in fifty minutes. Estimates of cost of dredging operations depend so largely on local conditions that the figures often current are delusive. It must be borne in mind that hopper measurements of spoil average about twice that of the material *in situ*.

A typical instance of waterways across sandy flats is that of the Dee from Chester to the sea. The present route of the Dee is in great degree artificial. The natural channel of the river anciently hugged the Cheshire shore of the estuary, following a serpentine course and having a depth of 6 feet and upwards. In 1732 an Act was obtained ostensibly for the improvement of the river. Under the powers so conferred a straight canal was cut from Chester to Connah's Quay. At the same time extensive land reclamations on both sides of the stream were carried out. In all about 7000 acres were thus "inned". The result was the decline of the river as a trade route. With the object of increasing its depth a series of jetties were subsequently built, projecting at right angles from the Cheshire side, the Flintshire shore being mostly embanked. The effect of these jetties was to set up a swirling action at the extremity of each jetty or groyne. At such points deep pools were thus

created, and in the intermediate spaces, shoaling took place. A weir has also been built below Chester, the level of the crest of which is 11 feet 6 inches above the level of the bed of the river. The engineering blunders perpetrated have had a disastrous effect on what should have been a great artery of commerce. There is no physical or geographical reason why the Dee should not carry as large a volume of trade as the Mersey; but to correct the errors of the past will involve heavy expenditure and works requiring a long period in execution.

A strikingly successful dispersal of shoals in advance of a harbour occurred at Tampico, Mexico.[1]. At this spot the tidal movement is almost negligible, averaging 2 feet to 2 feet

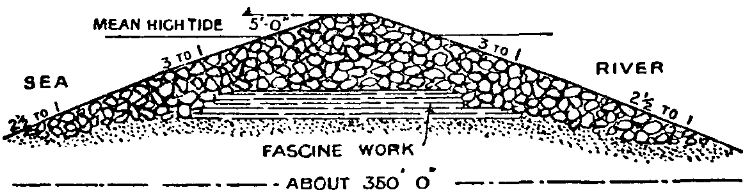


Fig. 5.—Cross-section of Training Wall, Tampico Harbour

6 inches. The river has at mean-flood stage a cross-section of about 25,000 square feet and a slope of about 7 inches in the mile. Owing to the drift of the Gulf Stream vast deposits of sand blocked the outlet of the river. A dredger was brought into play to loosen the bar, and jetties about 7000 feet in length and 950 feet apart were carried across the obstruction. The bar was of a stubborn character, and had numerous wrecks embedded in it. Depths of water before the works commenced were in places only a few feet. An opportune flood in July, 1893, continuing for twenty-two days, carried away the wrecks, and left a depth of 27 feet in its wake within and without the harbour entrance. The velocity of the flood was 8.2 miles per hour, and the total amount of material it carried into the Gulf of Mexico and dispersed was nearly 9,000,000 cubic yards. The maximum section of the jetty constructed on the windward side of the channel is shown in fig. 5.

[1] "The Tampico Harbour Works, Mexico" (Dr. E. L. Corthell), *Proc. Inst. C. E.*, Vol. CXXV, pp. 243-81.

The training of the mouth of the Mississippi affords a notable example of a similar character. In this case two parallel jetties were run seawards a distance of 2¼ miles. The effective width of the channel through the jetties was about 700 feet. In this instance willow mattresses and fascines on the Dutch system were adopted. These were partially loaded with stone, and, where the sea exposure is heaviest, with concrete blocks weighing from 20 to 70 tons. The depth of water in the entrance is now about 30 feet. A section of the fascine wall so constructed is shown in fig. 6.

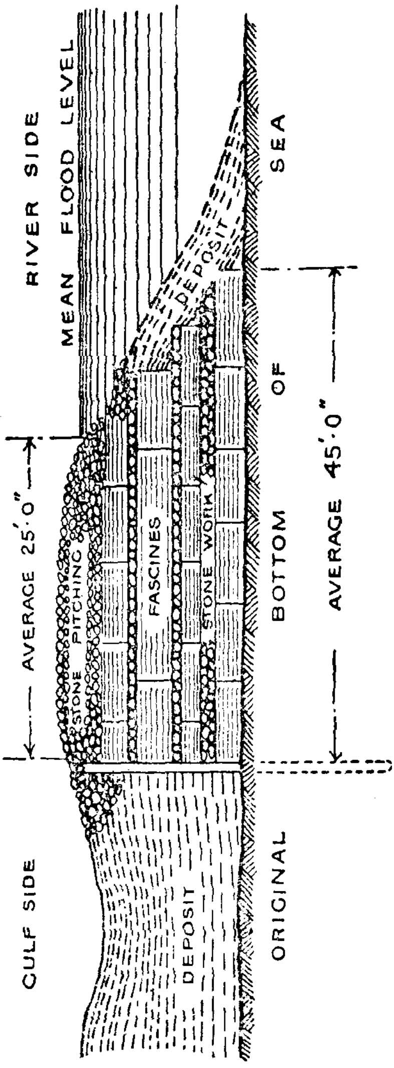


Fig. 6.—Cross-section of Training Wall, River Mississippi

Estuarial sand-bars, when dispersed, are apt to recur. They consist in section of under-water peaks, sometimes rising steeply to great heights above the sea bed. Although the tidal ebb and flow passes across them at high-current velocities, they often maintain an inclination steeper than the angle of repose of the sand composing them. When a gale of exceptional violence disturbs or partially levels them, with the recurrence of normal weather conditions they will pile up afresh in remarkably short intervals of time.

The problem of keeping down a harbour bar, unless expendi-

ture on an ample scale is forthcoming, is one of the most troublesome in the engineering of sea works. This is especially the case in small harbours, the tidal compartments of the rivers behind which are perhaps studded with obstructions to tidal flow. Such harbours are usually slowly evolved, and depend on annual revenue for improvement, a condition under which hand-to-mouth methods of finance are imperative.

The Firth of Forth affords an instance of a barless waterway, a condition due (1) to the gradual contraction of the inlet from the sea landwards, (2) its land shelter, (3) a conformation such that heavy seas cannot plough up the bed of its channel. On the East Anglian coast a notable contrast exists between the harbours of Yarmouth and Lowestoft, only a few miles apart. At the former harbour the outlet and approaches are deep by reason of the fact that the Yare and its tributaries bring down a great volume of land backwater and afford vast areas for the tidal flow to fill. At Lowestoft comparatively little tidal water enters the harbour, with the result that heavy dredging has to be resorted to to keep even the shifting and dangerous approaches to the port in being.

Upland and Tidal Waters.—The question of the relative value of land waters and tidal ebb and flow in producing stability and equilibrium in the *régime* of a river has been much discussed. The outlet of a river is the proper section to be first attacked in carrying out a system of regulation, and every step taken should be part of a comprehensive scheme of operations. The entrance of a river may consist of:—

1. Piers running into the sea, generally barred or impeded with shoal water.
2. A natural channel debouching directly into the sea.
3. The same cutting its way through flats of sand and mud.
4. An estuary.

Estuarial conditions may exist in combination with either of the others.

Entrance piers may be either solid constructions of timber or concrete, forming walls approximating to the vertical; or skeleton structures, the lower tiers of which are carried up solid to a

few feet above low water. Piers projected across shingle or sandy foreshores constitute in effect groynes arresting the littoral movement of drift. As such, unless designed with skill, they are apt to set up irregular shoaling and bars outside the harbour mouth. The contours of the bars which form in advance of them are in plan mostly sickle- or horseshoe-shaped.

The relative lengths and overlapping of entrance piers are matters which have frequently made or marred a harbour design. Thus at Durban harbour, South Africa,[1] the governing authority overruled the judgment of the engineers as to the design of the entrance piers, and, for a period of nearly sixty years, the harbour was of inadequate depth and one of the most uneasy on the South African littoral. This was mainly by reason of the fact that the south pier, as built and extended, persistently overlapped the north pier. Ultimately piers of equal length were adopted. The economy of the drift was thus changed, and the harbour now shows progressive deepening and commercial value.

In some instances a leeward pier has been so laid out as to act as a sand trap, thus threatening with extinction the harbour it was built to serve.

The ratio between the necessary tidal volume of water entering a harbour and the sectional area below low water of its entrance, in order to attain and maintain a given working depth of water, is variable. It appears that at Durban 1400 cubic yards of tidal volume per square foot of section of low-water channel sufficed to maintain or slightly increase depths of 33 feet and upwards, whereas, at the entrance channel of Cork harbour, 1050 cubic yards per foot of section secured complete scouring effect up to depths of 60 feet.

Flushing reservoirs have been devised in many localities, but their effects are apt to be capricious and irregular. The sudden release of a large volume of effluent water under a considerable head will dig deep pits in the vicinity of the reservoir and redeposit the scoured material in ridges or shoals, unless

[1] "Durban Harbour, South Africa" (C. W. Methven), *Proc. Inst. C. E.*, Vol. CXCIII, pp. 1–122.

the works are designed with much care. Experiments made with pneumatic erosion point to that expedient as a probable means of disturbing and throwing into suspension troublesome shoals, so that the force of the ebb may be enabled to carry them seawards. Mechanical erosion on the same principle has been applied successfully.

When remodelling the route of a tortuous river one matter of importance to be studied is the variation of geological formation along its course. In laying out channel curves full advantage should be taken of the comparative resistances of the strata to the impact of flow of tidal water. Broad principles only can be predicated in relation to the design of such schemes, as each problem has to be evolved on its individual merits. The motion of flowing water under the force of gravitation follows a rotative path, and its particles ricochet on meeting an obstruction. The resultant of these combined motions in the deeper areas of a stream is a downward, boring action tending to erode soft soil and redeposit it in slacker water.

The dynamic force of a stream is particularly active on its concave surfaces by reason of the transverse swirling action set up as it swings round a bend. The water gradient thus created results in a raking effect across the bed of the river, producing a deepening of the inner area of concavity and a shoaling on its outer area on or near the opposite shore. Plate II shows the cross-section of the Thames in a straight run at Long Reach. It will be noted that on both shores the batter of the river banks is coincident and the river bed fairly uniform in depth. Plate II also shows a section of the river through St. Clement's Reach, Greenhithe. The currents on the concave (Essex) shore have in this section produced a steep gradient and excavated the river bed to great depths. On the Kentish (convex) shore the gradient of the river bank is relatively flat and the river bed shoal. The navigation channel, or thalweg, for large vessels round such bends naturally follows the deeper water or the track of concavity. If the river section shown in this plate had been unduly contracted at the bend its lack of symmetry would have been relatively increased both on its shoal and scoured sides.

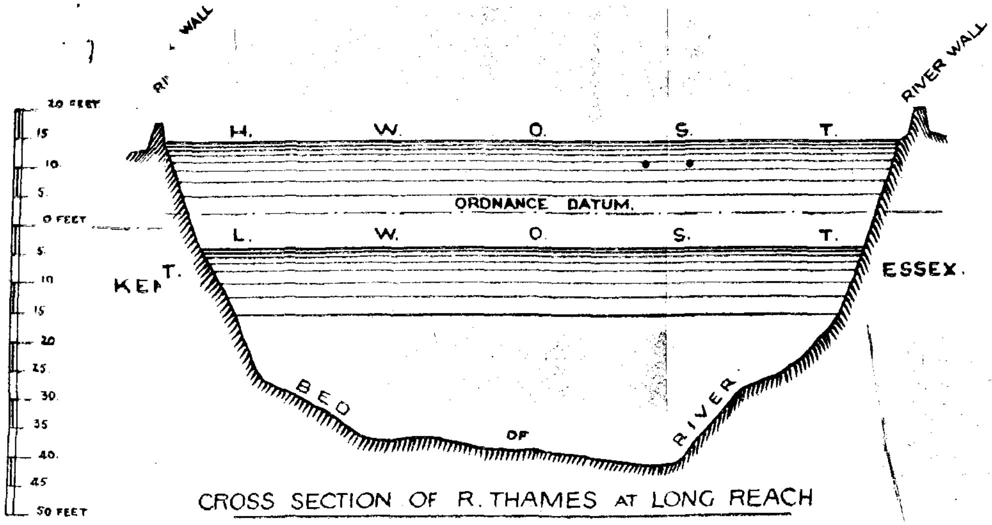
The welling up of the water caused by this action may be quite considerable. In the proximity of the entrance of the Alexandra Dock, Hull, the water-level at spring tides is about 19 inches higher than that of the opposite shore, two miles away. The transverse raking effect thus set up in the bed of a stream does not, however, appear to affect materially the flow of the main body of the river.

Owing to the character of its alluvial deposits the Thames, below London, has been moulded into an admirable carrier of world trade by reason both of its natural economy and of the prevision of its authorities of control.

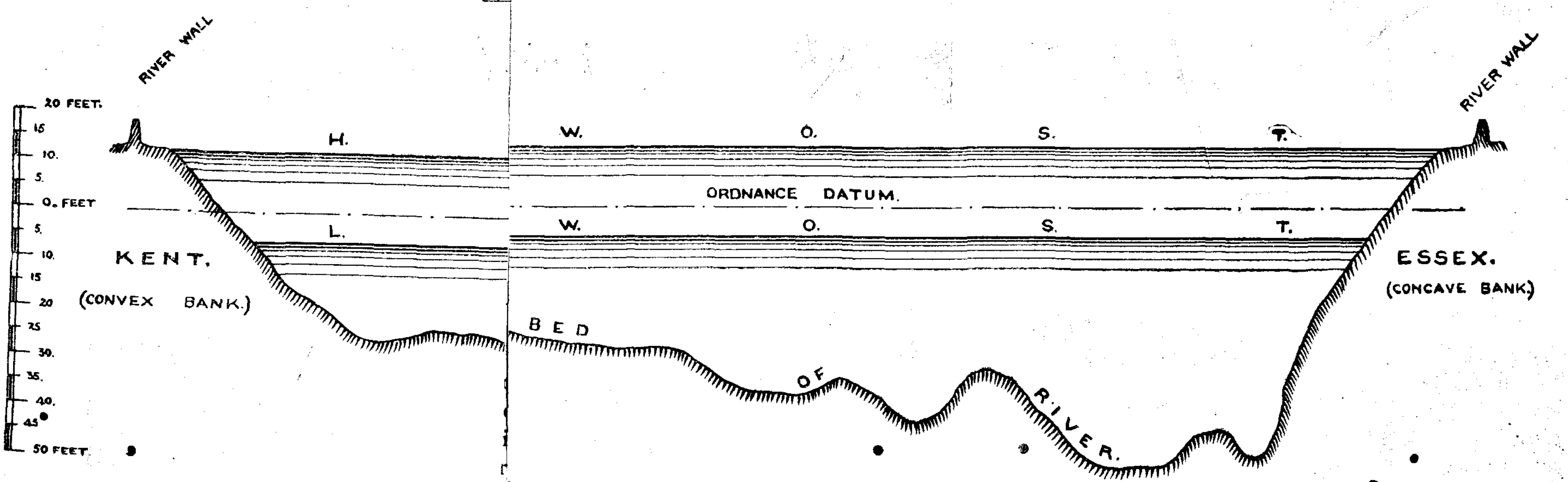
With the growth of the size of merchant ships the problem of the classification of their traffic has become more serious. It is probable that the tendency to cater by means of deep-water quays for vessels of extreme draught at points near the mouth of rivers, where greater depths of water naturally exist, reserving up-river accommodation for ships of less draught, will be accentuated. Trade will inevitably follow geographical conditions.

River Velocities.—Observations have been made by many investigators with the object of defining by formula the laws of stream velocity at varying depths of a channel and also the retardation of velocity due to obstructions in its course. The formulæ thus evolved are to be found in many handbooks. In any serious problem of river regulation exhaustive current observations are essential.

The volume of discharge of a waterway is obtained by multiplying its cross-sectional area by its mean velocity. To ascertain mean velocity observations by current meter or the velocity rod may be taken. Inference from surface velocity is more often resorted to. Owing to the varying rugosity of the bed of a stream, the above expedients furnish, however, an approximation only. It is obvious that the shape of the channel and the obstruction of weeds and other under-water impediments are varying factors which affect the issue. The problem can, nevertheless, be worked out with sufficient closeness for practical purposes by observation and the assistance of the published hydraulic tables.



CROSS SECTION OF R. THAMES AT LONG REACH



CROSS SECTION OF RIVER THAMES AT ST CLEMENTS REACH

abate or disappear. On the river Tsien-tang-Kiang[1] bore effects exist in an unexampled degree. As the flood travels across the sand there is a difference of level of 19 feet at springs between the water on the outside of the bar and that in the mouth of the river, a distance of about 20 miles. The measured speed of this flood having a gradient of about one foot per mile is 14.6 miles per hour. The bore has a breadth of 1800 yards, and forms a cascade 8 to 12 feet high. It strikes the outlet of the river at an angle of 40 to 70 degrees, and its roar is audible 14 or 15 miles away, an hour and twenty minutes before arriving. The bore maintains its breadth, height, speed, and regular appearance for 12 to 15 miles above the mouth of the river. At the city of Hang-chau, 24 miles from the mouth, the tidal range drops from 19½ feet to 6 feet.

The ancient devices of the Chinese to protect the native river boats from the effects of the bore have been adopted for the last eight or nine hundred years and still persist. The river is embanked for a distance of about 30 miles, and the top of the sea-wall is 3 to 9 feet above high-water spring tides. The embankment is faced with stone, and at numerous places by the river-side stone platforms enclosed by piles are constructed. One such platform is 1100 yards long and 20 feet wide. At both ends of these platforms buttresses are constructed parallel to the river wall. The bore as it travels along the banks is deflected by these buttresses into the middle of the river, and the junk master is thus enabled to take shelter from the destructive force of the tidal wave. Within the shield of a platform his junk slides harmlessly up and down the face of the slope of the embankment.

Working Models.—Within the last thirty years the practice of experimenting with working models of a tidal estuary before laying out new works for regulating it, has been initiated. Professor Osborne Reynolds's paper before the British Association in 1887 first called attention to the utility of this procedure. The British Association in 1889 appointed a committee to investigate, by means of working models, the action of waves and

[1] "The Bore of the Tsien-tang-Kiang" (Commander W. U. Moore, R.N.), *Proc. Inst. C. E.*, Vol. XCIX, pp. 297-304.

currents on the beds and foreshores of estuaries. The late L. F. Vernon-Harcourt adopted this expedient when studying the problem of training walls for the sea outlet of the River Seine, and in 1889 communicated the results of his investigations to the Royal Society.[1] The French Government subsequently had a model constructed under the advice of M. Mengin, the engineer in charge.

Experience of tests made with such models has shown their use to be highly valuable. Notwithstanding the fact that the vertical and horizontal scales employed for making such models are necessarily different, the records so obtained afford a close insight into the prospective effects of a defined scheme of works. In a model of the Mersey the horizontal scale adopted was 2 inches to the mile, the vertical scale 80 feet to the inch. The tide period was 42 seconds. After running the model for a period of 2000 tides, the existing natural contours and channels of the river were found to be reproduced with remarkable fidelity. By working a model for a few hours, and simulating repeated tidal effect, data can be demonstrated which would involve long periods of costly observation. While exceptional gales cause temporary derangement of estuarial conditions, the regular movements of the forces of Nature bring such conditions back to the normal, and the play of this action can be watched by operating a model.

The reports above specified describe how such models can be constructed. It is probable that no scheme of operations for the regulation of estuaries or tidal flats involving large outlay will in the future be organized without supplementing the preliminary investigations on the site by the evidence of working models.

[1] "The Principle of Training Rivers through Tidal Estuaries, as illustrated by Investigations into the Methods of Improving the Navigation Channels of the Estuary of the Seine" (L. F. Vernon-Harcourt), *Proc. Royal Society*, 1889.

CHAPTER III

The Foreshore

According to the Office of Woods the United Kingdom possesses a total frontage of coast foreshore at high-water line of 7906 miles; the total area between high-water and low-water mark is 619,999 acres. On the same authority the total length of river frontage at high-water line is 11,081 miles; the acreage between high-water and low-water mark of rivers is 175,722 acres.

The Director-General of Ordnance Survey (Colonel R. C. Hellard, R.E.) stated in evidence before the Coast Erosion Commission that in thirty-three years (between 1863 and 1896), so far as the official surveys enabled him to ascertain, there had been in England an accretion of land of 35,444 acres, an erosion of 4692 acres, or a net gain of about 30,750 acres of rateable land.

A definition of the term "coast foreshore" is not easy. It is synonymous with the word "seashore". In legal documents the *littus maris* is defined as "that ground between the ordinary high-water and low-water mark". Otherwise stated, the shore "is confined to the flux and reflux of the sea at ordinary tides". The ambiguity of the above definitions has been the cause of endless litigation. It is obvious that the term "ordinary tides" is capable of several definitions. The highest equinoctial spring tides occur in the natural order of things, and are in this sense "ordinary".

From the evidence of the Director-General, it would appear that there has been a lack of continuity of method in the mapping of the coast-line of Great Britain below high-water level. After the legal limits of the foreshore were defined by

Court decision as those "between high- and low-water marks of ordinary tides", the basis of survey appears to have been modified. The Director-General points out that although in a given locality high-water line might remain constant the simultaneous position of low-water line might fluctuate, causing, as the case might be, a steepening or flattening of the gradient of the shore, which in its turn would affect its area. In estimating the aggregate gain or loss due to accretion and erosion the question of the inclusion or exclusion of the foreshore constitutes an important and precarious factor, as, if the foreshore be excluded and the area of terra firma only be considered, obviously this element of uncertainty would be to a large extent eliminated. The Ordnance Survey authorities were in fact faced with the primitive dilemma as to what constitutes land and what water. Moreover, in many instances land reclamation was carried out, increasing the area of the soil of Great Britain by artificial means. Mean sea-level is the most reliable datum in respect of plotting the contours of tidal range, and on Ordnance maps it is stated that the altitudes are given in feet above the assumed mean level of the sea at Liverpool, which is 0.650 feet below the general mean level of the sea. Apparently until 1913 mean sea-level was not ascertained with accuracy. It would appear, therefore, to be legitimate to take the official statements with regard to the estimated increase in land area of the kingdom with considerable qualification. The recommendation of the Commission under this head is as follows:—

"It would be of advantage if the Ordnance and Geological Surveys could take steps to ascertain from time to time whether, and, if so, to what extent, changes in the relative levels of land and sea are taking place".

Arising out of a recent case, a paper read before the Law Society[1] is of interest. It may perhaps be noted that the Ordnance Survey Department relies upon the case of Attorney-General *v.* Chambers for a definition of the term "foreshore". In this case the coastal area overflowed by the average of

[1] "The Foreshore" (J. W. F. Jacques), Law Society's Birmingham Meeting, 1908. (Spottiswoode & Co.)

medium tides in each quarter of the lunar revolution during the year was assumed to delimit the rights of the Crown on the seashore.

In the specific case above referred to ("Pierson *v.* Burnham, U.D.C."), the Board of Trade had granted in 1897 a lease of "the foreshore" to the Burnham (Somerset) U.D.C., using the Ordnance Survey map as indicating its boundary. The Ordnance Survey Department had revised their map in 1897, and again in 1902. The case turned upon the right of the contiguous owner to fence his land, which was above the flooding limit of all save extraordinary spring tides. In answer to inquiry by the plaintiff's solicitor, the Director-General of Ordnance Surveys stated that, in the preparation of Ordnance maps, tide lines were not referred to any datum, but were represented by the contour of mean tidal flow between springs and neaps. In reply to subsequent inquiry he stated that high-water contours were obtained by actual survey taken at the fourth tide before new and full moon. It further appeared that, as must obviously have been the case, the Ordnance surveyors actually took their observations on a "selected tide". Now unless wind conditions are absolutely still when such survey is undertaken, it is obvious that the range of the tide might be materially raised or depressed from this cause. Again, the summit flow of tidal travel is so transient that its exact definition by survey would be wellnigh impossible.

From the above considerations it appeared to those engaged in the case that the only practicable method of delimiting tidal flow was that of survey *plus* calculation. The perpendicular height of the "medium tide" having been taken from the nearest observation point given in the Admiralty tide-tables of the year, and the necessary correction made for its variation, as ascertained by survey, for the point actually under observation, the contour line on the foreshore would by this method be ascertained by levelling from the Ordnance bench marks. Thus would contour lines indicating high-water level be accurately defined on a plan, and such contours would be based upon the known data of tidal gauges, disregarding the precarious observations of a fleeting line of tideway.

The difficulty of giving verbal expression to the delimitation of foreshore rights is doubtless considerable, for definition is ever an ill-fitting garment. The first consideration of litigants may pretty frequently be expressed in the following question: To what extent can we with legal security remove our neighbour's landmark?

The ownership of lands contiguous to a shifting foreshore has been the cause of many legal decisions, for the law in Great Britain in this connection appears to rest largely on custom. In the case of Scratton *v.* Brown, it was held that the frontier of a freehold held under grants from the Crown advances or recedes with the corresponding accretion or erosion of the foreshore. In the case of Rex *v.* Lord Yarborough, it was decided that "accretion, if gradual, belongs to the owner of the adjoining property". In the case of Lowe *v.* Govett, the decision was: "A piece of land covered with land and sea weed, and overflowed by extraordinary spring tides, but not by the mean ordinary tides, belongs to the adjoining owner, and that without the exercise of any acts of ownership". Grounds upon which claim to ownership has been founded are numerous, but the legal issue in this respect is somewhat wide of the present discussion. The latest decision would appear to be summed thus, in the case Attorney-General *v.* Emerson: "A subject can only establish a title to any part of the foreshore, either by proving an express grant thereof from the Crown, or by giving evidence from which such a grant, though not capable of being produced, can be presumed".

The rights of the public to wander at will over the sea beach, and to use the foreshore for walking, riding, driving, drying nets, hauling up boats, bathing, and sport, have given rise to much litigation. In the case quoted above (Pierson *v.* Burnham, U.D.C.), it was held that to assume the rights of the public over a shore to be similar to those over a highway dedicated to public use was unreasonable and untenable; that because an owner of waste land adjoining a foreshore and occasionally overflowed allowed the public to wander at will over the same, he thereby created no public right. If it were attempted to establish such a right, the only result would be that

owners of littoral lands would be compelled to fence them, in order to avoid establishing inconvenient rights. Such admission would be distinctly to the detriment of the public, as, if conceded, lands capable of being developed into the sea front of a prospective watering-place would be jealously fended from the incursion of the public.

The state of the law in respect of the ownership of seaside lands in foreign countries may be briefly summarized as follows:[1]—

France.—Foreshore lands covered at high water form part of the *Domaine Public National,* and are administered by the *Département des Travaux Publics.* The State stands aloof from responsibility in respect of erosion, except that where owners form *Associations Syndicales de Défense* the State sometimes grants subventions. The landowners have no right to remove sand or shingle except with the authority of the *Préfet* or *Ministre des Travaux Publics*, the price for same being fixed by the *Domaines de l'État.* If the sea recedes, such recession becomes the property of the State; if the sea encroaches, the landowner receives no indemnity from the State.

Belgium.—The ownership of the foreshore is vested as in France. The definition of the phrase "foreshore" given by the *Ordonnance de la Marine* of 1681, is that area covered and uncovered at new and full moons by the greatest flood in the month of March. The limit actually adopted to-day is the line assumed by the tidal curve on the coast 5.21 metres above zero, Ostend, which mark corresponds with the average level of low-water spring tides. From the tidal curve thus indicated is defined the dividing line between private property and that under the control of the *Domaine Public.* Thus it will be noted that the practice adopted by the State Departments of Belgium accords with the method evolved by those engaged in the Burnham case, cited above, as the only plan of delimitation consistent with accuracy. The State in Belgium assumes no responsibility in respect of protection of the coast-line or the effects of erosion. The rights of littoral owners do not extend beyond the boundaries defined above, and foreshore lands

[1] "Coast Erosion" (A. E. Carey), *Proc. Inst. C. E.*, Vol. CLIX, pp. 1–103.

formed by the insensible recession of the sea become the property of the State, unless there is some title or prescriptive right to the contrary—i.e. unless these lands are possessed by virtue of an act of acquisition or by thirty years' occupation.

Italy.—Under the Civil Code, ports, harbours, foreshores, and waterways in connection with same, are the property of the Crown. This principle is based upon that of Roman law, whereby property essential to public utility cannot become the exclusive property of anyone, but is vested in the State. Owing to the difference between tidal conditions in the Mediterranean and the Ocean, the period for the observation of delimitation between private and public ownership in the former case is that of winter, when tidal range is at its maximum. The foreshore comes under the jurisdiction of the Minister of Finance, its use and control under the Minister of Marine, and all works affecting it must be sanctioned by the Minister of Public Works. Sand and shingle can only be removed with official consent. In the event of either recession or erosion of a coast-line, the transformed foreshore becomes Crown property. A landowner whose land is washed away has no redress against the State, unless such encroachment is due to dredging or the removal of protective embankments, when those responsible for the damage would be legally liable.

Denmark.—Foreshores are private property: their control is in the hands of adjoining landowners.

Norway.—The Danish rule holds good, private rights extending, moreover, to a depth 2 metres below low water.

United States.—In the United States the legal status of the foreshore is subject to the varying law of particular States. In the States of Maine, New Hampshire, and Massachusetts the law provides that private ownership on the foreshore extends to low-water mark, where the sea does not ebb more than 100 rods, but not beyond this limit, subject, however, to the rights of navigation. Littoral proprietors may thus exclude navigation from their own flats by building wharves or other structures to low-water mark, and it has been held that they may fill up their frontage, and thus prevent the ebb and flow of the tide, without

being liable in damages. In Connecticut the rights and privileges of littoral proprietors extend to low-water mark, subject to State regulation. In New York the landowner has no right of property between high-water and low-water mark. He has no right to reclaim, as against the State, and is not entitled to compensation should a railway be constructed along the water-front of his premises. In New Jersey the State owns the shore, and the littoral proprietors have no legal right to carry out works upon it. The State may groyne any portion of the shore without making compensation to the owners of the adjacent lands, but when shore lands are reclaimed they become the property of the littoral proprietor, and cannot be taken for public usage or granted by the State to other persons without compensation. In Virginia the littoral owner possesses exclusive rights and privileges to low-water mark, and, if not interfering with navigation, may build wharves below low-water mark. In North Carolina the State can only grant land under navigable water for wharf purposes, but for this purpose the littoral owner may carry his works "as far as deep water", and they then become his absolute property. In South Carolina the State owns the land under navigable waters by common law. In Florida the shore is vested by statute in the littoral owners. In Louisiana strips of land near the mouth of the Mississippi, including land not submerged but subject to overflow, belong to the State. In California private ownership extends to high-water mark, the shore being the property of the State; and in Oregon similar rights exist to those in the State of Florida.

Turning aside from legal subtleties, the foreshore constitutes to the engineer a terrain generally covered by a travelling medium of defence, consisting of sand, shingle, or both. In its rear may be sea-walls, cliffs, or embankments. From the slope of the sea marge, and the nature of the material with which it is clothed, the degree of its storm exposure may be safely surmised. If the shore be flat, consisting of wide stretches of muddy sand, with or without a narrow fringe of shingle or stone along its landward frontage, it is safe to infer the absence of severe gale conditions. If, on the other hand, a foreshore con-

sists of steep ridges of shingle or boulders, intermixed with little or no sand, such economy points to its being subject to periodical wave-battering.

One of the first matters to be studied in gauging a coast-line *régime* is its geological economy. Obviously, the existence of primary or igneous rocks spells resistance to erosive forces; the presence of clay or friable sandstone means that undermining by or invasion of the sea can only be counteracted by artificial expedient.

The presence of vast accumulations of sand and shingle, forming a buffer territory between land and water, is a phenomenon which requires some comment. The explanation of its existence usually offered is that it represents the degradation of contiguous land; that as cliffs fall, or fresh tracts of coast-line are attacked by encroachment of the sea, the flint and stone they contain are riddled out, and thus is amassed a capital of protective medium of defence. Attrition, due to wind-waves, then breaks down boulders into shingle, and shingle into sand. This explanation is, however, only half the story. The fall of chalk cliffs is intermittent, and the amount of flint derived from this source would be relatively insignificant. East of Folkestone the white chalk dies out, and the grey chalk running towards Dover is flintless.

The only solution of the problem which fits the facts is that in our south-east coast shingle deposits we have the *débris* of the denudation of Tertiary gravels and sands, which overlay the chalk before the floods succeeding the Glacial epochs scoured and moulded the surface of the chalk. It is probable that the crest of the dome of deposit reached a height of 2000 feet above present sea-level, when the North and South Downs formed one continuous sheet of chalk, covered by gravel deposits. On other portions of the coast-line (notably the east coast), the shingle deposits have in the main been derived from Glacial Drift, which assumed vast proportions in the late Glacial Period. The result of these remote geological events has been that our coast-line is fendered by a belt of protecting medium. It is obvious that this medium, which is kept in circulation by natural forces, constitutes in effect a bank in which our capital

of safety is lodged, and that its serious depletion amounts to an act of criminal folly, which the State should intervene to prevent.

The depth at which mud reposes on a sea bed is good evidence as an index of the severity of wave conditions. Airy has shown by calculation that heavy ground-swell scours the sea bed at a depth of 100 fathoms. Lobster pots on the Devonshire coast become filled with sand at a depth of 30 fathoms. Off the west coast of Ireland mud comes to rest in 40 to 60 fathoms water. In the sheltered parts of the east coast loughs it lies at depths of 5 fathoms.

A wave trap or spending beach is indispensable to the tranquillity of an enclosed harbour or landlocked basin, especially where tidal range is considerable. The run of the sea, after passing the entrance piers of a harbour, assumes the aspect of a miniature bore. Its impetus is cumulative. When the wave thus developed reaches a shelving beach, or a recess leading to slob land, its force is dissipated. If a harbour be so designed that the run entering it encounters a wall or other barrier approximating to the vertical, the recoil of the oncoming wave induces prolonged oscillation. It has been proved experimentally, that in a box 20 feet long, ¼-inch to ½-inch waves beat backwards and forwards at least sixty times. Such action causes the accumulation of a transverse ridge or bar running centrally across the middle of the area of disturbance, at right angles to the line of the run of the waves.

A notable instance of this effect is that of the harbour at Torquay (fig. 7). The small inner harbour is of ancient construction, and sufficed for the minor traffic of the district. In order to enclose a larger area of water, the western arm was subsequently built. The opening of the new harbour faces west-south-west. Concurrently a reclamation of foreshore land was carried out, a nearly vertical wall being substituted for the old sloping sea marge, which previously constituted an efficient wave-breaker. The result of these works has been that both the inner and outer harbours have for practical purposes been gutted, as the mud and sand which formerly lay in the harbour have been scoured away and carried to sea. Between the nearly

vertical faces of the western arm and of the new alignment of foreshore, any undulations which pass into the harbour are repeatedly reflected. The result is an uneasy harbour under normal conditions, and in gales, a condition of things such that the harbour is almost unsafe for the small craft frequenting it. It is probable that quite a moderate expenditure, reproducing conditions which make for tranquillity, would be effective.

The charm of sea work consists largely in the fact of its

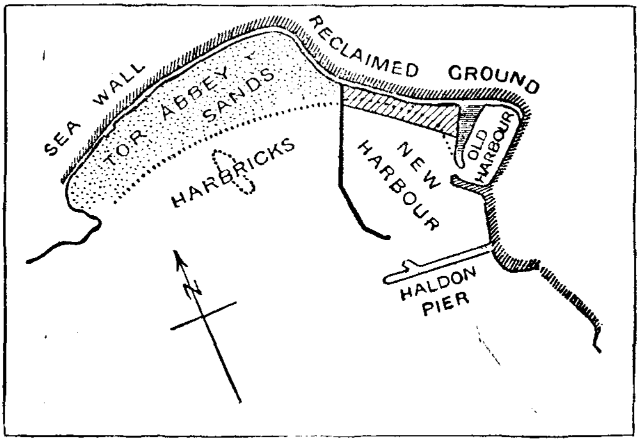


Fig. 7.—Diagram of Torquay Harbour

infinite variety. Its merit is that it cannot be standardized. No two stretches of coast-line are alike. Each novel set of conditions has to be absorbed into the inner consciousness of the engineer who would successfully evolve a scheme of artificial control. It is the interaction of the forces and the apparent caprice of sea action that puzzle him. The man to whom the pitfalls of such a problem have grown instinctive in some measure recovers the primary faculty which civilization is apt to blunt. Unconsciously, he sets to work to weave a chain of cause and effect by which storm and current may be brought into subjection to his purpose.

There are two schools of foreshore engineers. One school seeks to establish as an axiom the theory that the travel of

littoral drift is due to tidal action, the other that it is caused by wave action. The march of the circulating medium of defence is, in fact, represented by the sum of all the forces operating on a coast-line. Wind-waves are the prime cause. The tidal impulse plays its part. Wind creates great sand-storms, producing vast deposits above high-water line, and the recoil from a cliff or sea-wall of heavy swell scours and drags down shingle, bringing it within reach of the oblique stroke of running seas. That the tidal force is not the sole or principal operative action in the travel of drift is evidenced by the fact that on coast-lines where tidal lift is negligible the same familiar phenomena are to be met with.

The column of drift oscillates coastwise, and on the recession of the tide is left alternately heaped into terraces and dragged down into slopes. The prevailing wind in Northern Europe is west-south-west. Taking an exposed coast-line, such as that fronting the English Channel, running roughly east and west, the effect of wind-waves varies greatly. An off-shore wind causes the beach material to heap up, a due on-shore wind sweeps it down. Between these two extremes the variations of angle of stroke cause all the familiar gradations of phenomena. Where the trend of a coast affords protection from sea exposure and the worst conditions of wind, the severity of the problem of erosion is lessened. Thus under the lee of an outstanding headland, such as the Start, the shore can be maintained with comparatively little difficulty. It is beyond the zone of such protection that the full rigour of erosion results. For instance, between the Start and Sidmouth the inroads of the sea are less acute than is the case on the frontage to the east, by reason of the fact that the former strip of foreshore is partially sheltered.

Oceanic waves advance in columns from the open sea. As they approach the shore their diagram of forces changes. From waves of oscillation they become waves of translation. A wave of oscillation is a mere carrier of momentum. The impetus it has acquired sets up a vertical spinning action. Its motion is the resultant of the horizontal force of the wind and the vertical force of gravitation. The contour of a deep-sea wave

is cycloidal, and this approximates to an ellipse in approaching shoal water. The force conveyed in an oscillatory wave revolves in a circular movement at the crest. As may be readily observed, an object floating on an oscillatory wave is not impelled forward by that wave—it drifts with the current. From the point when the wave becomes translatory in form its whole mass travels onward in the manner of a flowing stream. When its height attains one-third of its length the wave breaks. The translatory waves that affect a foreshore plough up the beach constituents, and the problem of defence works is to hold the shingle and sand up to their work, so that the shore shall not be denuded of its natural protection.

Obviously the shape of the shore in section is a factor of first-rate importance. The normal forces of attack and the contours of a sea marge are complementary. If a shore be neglected its contour changes, its gradient grows dangerously steep, and the coast-line suffers erosion.

The mechanical action of the off-shore wind in heaping up a foreshore is somewhat obscure. Presumably by checking the onrush of the crest it upsets the equilibrium of the wave. The motion of the crest being retarded, the base of the wave sets up an undertowing action. The beach materials are thus pushed up the under-water slope, and, the scouring action of the crest being absent, they accumulate.

It must be borne in mind that the flood tide is both longer and stronger than the ebb, and therefore that, so far as the action of the tidal current is effective, it operates by driving the beach constituents in the direction of the flood. Wave action, when oblique to the shore, causes a series of unsymmetrical impulses. The impinging wave drives a column of shingle up the slope of the foreshore, the impelling force becomes exhausted, and the water escapes through the beach. The recoil of the spent water follows the most direct line of travel, i.e. that at right angles to the coast-line. It has pushed a certain quantity of beach material beyond the power of the recoil and dragged the balance down again, and thus the march of that material follows a zigzag, saw-tooth line of travel. The operative wind-waves in the English Channel are those produced by the

impulsion of the winds from west to south-west. In the North Sea, owing to the land shelter from the west, winds round about the north-east are those setting up the severest wind-waves.

Land springs frequently disintegrate the base of a cliff or disturb a foreshore to such a degree that the recurrent effect of gales is increased. Wherever cliffs of Tertiary clay abut on a foreshore their plasticity is a constant source of danger. They are apt to slide in the fashion of a glacier, and the pressures they cause can only be counteracted by heavy works.

Another action seldom allowed for is that set up where sea-walls or other littoral defences are built at or near the foot of a cliff. The weight of the cliff then causes the strata on which it is based to buckle, and the foundations of the sea-wall may thus be crushed out of line and the wall ruptured.

Another action which is certainly not negligible is the effect of the concussion of waves on the crust of the earth. The record of seismic disturbance is a registration of the ripple of oscillation conveyed by this action to a spot perhaps on the opposite side of the globe. Professor Milne's instruments proved that relatively trifling displacements of weight cause an appreciable tilting of the earth's crust, and Sir George Darwin calculated that the movement of the tide, the addition and subtraction of the weight of its waters, set up oscillatory disturbance inland for a distance of 100 miles.

In the planning of a seaside town these considerations are important. At some of the older watering-places the building area is pushed forward to within a few yards of high-water line. The wise course is to leave a wide belt of lawns or gardens between the sea beach and the houses; thus can long flat slopes be substituted for high sea-walls. A line of such walling is one of the best expedients conceivable for producing dangerous scour, and perforce it has to be supplemented by heavy groyning. The art of Dutch foreshore engineers relies on the methods which are the antithesis of such expedients. In that country of nicely adjusted equilibrium between land and sea Nature

is copied with fidelity, and easy slopes on which sea forces may spend themselves are universally substituted for the mere dead weight of upright walls, against which the momentum of waves may be absorbed by shattering blows.

The phenomenon of vast accumulations of shingle heaped to abnormal heights above high water by periodic gales requires some comment. In this connection a study of the geological antecedents of the coast-line under consideration is important. On the east coast what are termed "swashways" occur opposite lines of cliff. These consist of ridges of shingle and sand running parallel to the coast-line, distant some few hundred yards from it, with a waterway between such shingle bank and the shore. The cause of this, which is a fleeting effect, is the beating of ground-swell broadside on the coast-line. When such ground-swell ceases a swashway disappears. By direct impingement the breakers drag down the shingle and form a temporary ridge seawards. Formations such as the Chesil Bank fall under a completely different category. They are the result of geological upheaval and subsidence, being the remnants of ancient raised beaches. Starting from Start Point, and skirting the present coast-line, there is strong evidence of the existence of an ancient raised beach which once fringed the coast-line almost continuously.[1] Opposite the hamlet of Hallsands a remnant of this raised beach formerly existed until the unfortunate official permission for artificial denudation was given, as will be detailed later. On the west side of the River Dart a second raised beach exists, and remnants of others in the vicinity of Bury Head, Brixham. At Hope's Nose, Torquay, another raised beach exists, and at the point of Portland Bill a raised beach is again in evidence.

The conformation of the Chesil Bank is in many respects unique.[2] It is a vast breakwater of stones assembled from many sources. In the Dorchester Museum there is a collection

[1] "On the Origin of the Chesil Bank" (Joseph Prestwich), *Proc. Inst. C. E.*, Vol. XL, pp. 61–114.

[2] "Description of the Chesil Bank, with Remarks upon its Origin, the Causes which have contributed to its Formation and to the Movement of Shingle generally" (Sir John Coode), *Proc. Inst. C. E.*, Vol. XII, pp. 520–57.

of stones from the Bank, and these are in the following order of abundance:—

(*a*) Chalk flints;
(*b*) Greensand chert;
(*c*) Portland limestone and chert;
(*d*) Quartzites resembling those at Budleigh Salterton, and other far-travelled rocks of doubtful source.

In rear of the Bank is the Fleet, a fiord running between it and the mainland, and varying from ¼ mile to 1 mile in width. In this fiord tidal influences are insignificant save at its opening. By forces set up under the Channel currents the line of the ancient raised beach already described has been forced shorewards, the Chesil Bank being a remnant of it, the west end of the beach having been driven up to the shore opposite Abbotsbury. Between Plymouth and the coast of Brittany the Channel is about 112 miles wide. Between Portland Bill and Cap de la Hague the width is suddenly reduced to 60 miles, widening to the eastward again to over 100 miles. The effect of this sudden contraction is the creation of the Race of Portland on the north side and the Race of Alderney on the south side of the Channel. Off Portland Bill the velocity of the race is 5 or 6 knots. Under the stress of its currents, combined with the blow of heavy gales, the old shingle beach has been steadily pushed back and the present contours of the coast-line created. The Bank runs from Abbotsbury eastwards for a distance of 10¾ miles, having a width at the base of 500 feet at the west end, increasing to 600 feet at the east end. At the west end the crest normally rises 23 feet above high-water level; at the east end to a height of 43 feet. The foundation of the Bank is Kimmeridge clay, at a depth of 8 fathoms of water. The section of this natural mole is highly instructive. At its east end, from the crest to a depth of 4½ fathoms, it has a mean seaward slope of 1 in 5½; for the next 2 fathoms this flattens to 1 in 8, and to the base in 8 fathoms to 1 in 30. At its west end to a depth of 3½ fathoms the mean slope is 1 in 7; for the next 2 fathoms 1 in 11, and to the base in 6 fathoms 1 in 30. After the great storm of 1852 Sir John Coode took a series of sections, which showed that nearly 4,000,000 tons of shingle had been swept

down into deep water. In severe onshore gales the crest assumes a slope of 1 in 9. After a period of slack weather or offshore winds it is sometimes as steep as 1 in 2½.' One curious phenomenon on the Bank is the automatic grading of the stones composing it. Starting from the west end at Abbotsbury, the stones average about 1½ ounces, whereas at the east end they increase to about 13 ounces.

The late Mr. Clement Reid, F.R.S., has noted the great difference between the wear of pebbles from varying geological deposits. He points out the curious fact that on coast-lines which are entirely of chalk, the sand is not flint sand but quartz sand, and he states that the distinction between the two classes of sand under the microscope is quite easy. A flint pebble taken, say, from the Brighton beach, if carefully examined, will frequently be found flawed with a number of minute fissures, and the life of such a flint, in spite of its great hardness, would be considerably less than, say, a greenstone pebble from Penzance beach, the wear on which would be regular and slow, the pebble stone being polished by attrition to an extreme smoothness of surface.

The Chesil Bank, notwithstanding its enormous bulk, responds to the forces which normally operate on its face, i.e. the action of travel along the frontage of the shore under the impulsion of wind-waves and currents, and a movement bodily in the shoreward direction by the impact of gales. In storms vast quantities of shingle are thrown right over the crest on to the back of the bank. Moreover, owing to the fact that the Fleet, especially in its upper reaches, is hardly affected by the tides, and consequently approximates to mean sea-level, a difference in water-level on the two faces of the bank amounting to 10 feet or more occurs at spring tides and leads to active percolation from the sea to the Fleet. A striking result of this percolation is the removal of shingle from the foot of the landward slope with discharge of the same on to the shore of the Fleet. This shingle removal where it occurs keeps the slope of the bank on this side at the angle of repose for the materials, about 33 degrees. The profile of the bank shown in fig. 7A, besides showing the various topographical features, indicates by the dotted line the manner

of the cutting back of the slope and advance of the ejected shingle into the Fleet.

As percolation is localized and not continuous in space all along the bank, the result is a series of deep-cut ravines, each about 12 feet high on the lee face. (Plate IX, 1, p. 96.) Each ravine has a gully of discharge on its floor leading to a talus fan projecting into the Fleet. The aggregate of these talus fans forms a terrace (fig. 7A, T) some 70 feet wide, standing about 2 feet above the level of the water in the Fleet (Plate IX, 2).

The landward transport of shingle is therefore effected in

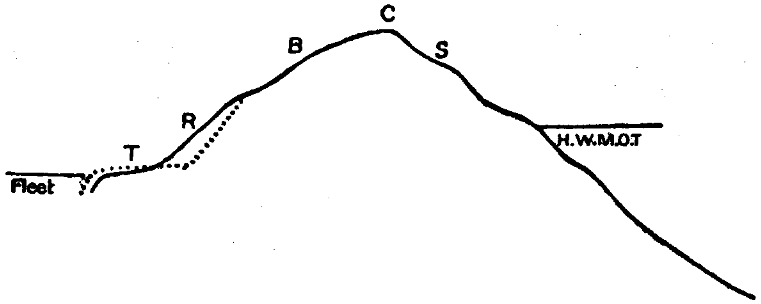


Fig. 7A.—Profile of the Chesil Bank East of its Point of Separation from the Land

The dotted line is to show the cutting back of a ravine and the transfer of the talus to the terrace. S, storm shelf; C, crest; B, back; R, ravine; T, terrace; H.W.M.O.T., high-water mark ordinary tides. The vertical scale is much exaggerated.

this case at two steps. It is thrown over the crest by storm waves on to the back, and then in consequence of the percolation slides down the critical slope and is ejected into the Fleet. Though data are not available as to the rate of movement of the bank as a whole, it is well known that the landward edge of the Fleet is continually retreating, no doubt as a consequence of encroachment by the bank.

The vegetation on a shingle bank is closely related to the mobility of the ground. Shingle in unstable equilibrium, as on a slope at the critical angle, is unsuitable for the establishment of plants; moreover, the seaward face in consequence of exposure is likewise too strenuous. On the dormant parts of a bank, however, a vegetation springs up, depending for its luxuriance on the amount of available plant food in the form

of humus contained in the bank. The plants of shingle beaches fall under two categories. There are those which germinate and establish directly upon the bank, and those, on the other hand, that occur on the ground over which the shingle drifts, and which rise up through the shingle and colonize it. The characteristic plants of shingle include the Sea Dock (*Rumex trigranulatus*), Horned Poppy (*Glaucium luteum*), Yellow Stone-crop (*Sedum acre*), Sea Campion (*Silene maritima*), the Sea Pea (*Lathyrus maritimus*), grasses such as *Triticum junceum*, *Festuca rubra*, and *Poa annua*, and the shrubby Sea Blite (*Suæda fruticosa*). This last-named as a stabilizer is most important, and its relation to shingle will be fully considered in Chapter VII. It occurs wild in this country on the Chesil Bank and on the coasts of Essex and Norfolk, and in Poole Harbour.

CHAPTER IV

The Function of Vegetation

Now that the physical conditions of the shore have been outlined, together with some of the problems which confront the maritime engineer,[1] it will be convenient to consider the relation of coastal vegetation to the phenomena of the shore, with particular reference to those special features which render plants pre-eminent as agents in the protection and growth of tidal and coast lands. Before proceeding further, there are certain general characteristics of the plant mechanism which must be clearly understood. A plant is a sedentary organism, and the first effective act of a seed or other plant germ is to take up a fixed abode. With the typical animal the procedure is quite different. An animal is largely a mobile pouch, or stomach, for the storage of the organic matter which forms its food. It hunts and collects its food, and this accounts for many of its outstanding characteristics.

The plant, however, is sedentary and draws nourishment from its surroundings. By the absorption of gaseous molecules from the air, and dissolved salts and water from the soil, it attracts to itself in conformity with the laws of physical diffusion the simple ingredients of its food. The nutritive problem of the green plant is a double one. It has to absorb these simple components of its food, carbon dioxide from the air, nitrates, phosphates and sulphates in solution from the soil, and to combine them into complex organic matter (carbohydrates, proteins,

[1] The term "marine engineer" has been adopted for engineers who are concerned in the design and propulsion of ships. It is suggested that the designation "maritime engineer" might be appropriately reserved for civil engineers who specialize in the construction of foreshore works and structures in the sea and allied waters.

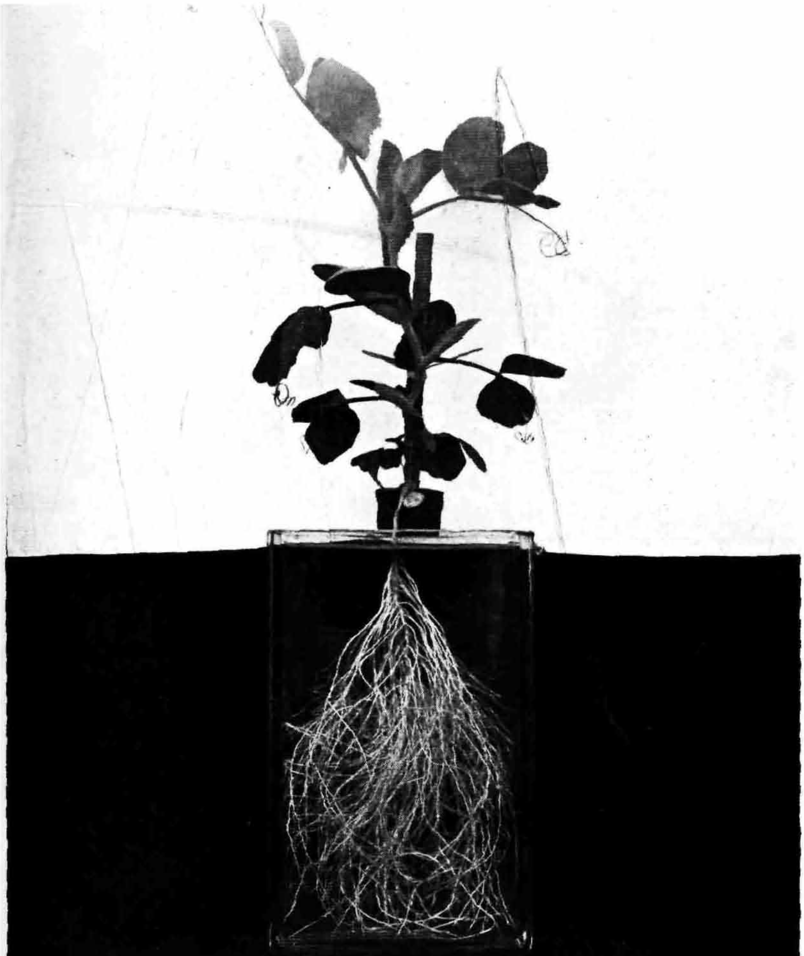


Photo. supplied by Dr. W. E. Brenchley

PEA PLANT GROWING IN A WATER-CULTURE SOLUTION

With Extensive Development of Root-system

&c.). In addition to this it has to assimilate or incorporate the latter into its fabric, i.e. to transform the organic foodstuffs which it manufactures into plant substance, just as a dog converts meat and biscuit into dog substance.

The organs concerned in these processes are the root and shoot systems, which are normally unfolded in the soil and in the air, respectively. Typically the root is an aggregate of slender filaments developed beneath the surface of the ground and bearing a closely-aggregated pile of minute tubules—extensions of the superficial cells—known as the root hairs. These roots, with their root hairs, occupy the interstices between the soil particles, and through their agency the water and dissolved salts of the soil gain entrance into the plant body.

The root system may consist of a principal root, which penetrates the ground, together with lateral roots, and yet other branches of the third degree. As a plant increases in age this primary root system is commonly supplemented by additional roots which arise directly from the stem, whilst in perennial plants, especially such as possess creeping underground stems, the whole of the roots will belong to this latter class.

Actually the root is a most extensive absorbent surface adapted to occupy the interstices of the soil, and to obtain therefrom the water and dissolved salts which clothe the surfaces of the soil particles. How extensive is the root system, and how thorough its exploration of the soil will be appreciated from the following example. (See also Plate III.) In a field of maize the roots occupy entirely the whole upper 3 feet of the field, and attain a density such that nowhere is a cubic inch of soil to be found not penetrated and explored by a rootlet.

An index of the work done by the root in water absorption is obtained from the fact that it has been ascertained that maize transpires (i.e. evaporates into the air) on the average 2.9 lb. per stalk *per diem.* This means that the crop planted in the ordinary way would take 244 tons of water from an acre of ground during the growing season, and this from a soil so dry that no mere pressure could express a drop of water from it.

This root system occupies and adjusts itself to the interstices of the soil, i.e. spaces filled with moisture-saturated air in

contact with the wet surfaces of the soil particles. The cellular membranes which clothe the root hairs and rootlets being from the nature of the case perfectly permeable to water, it follows that, if the root be exposed to air which is not saturated, it will give off moisture and dry up. The soil roots of a plant which has become partially or completely uprooted thus constitute its most vulnerable spot. In practice only roots which have developed *in situ* are of any service, and for their continued efficiency it is evident that they must not be disturbed.

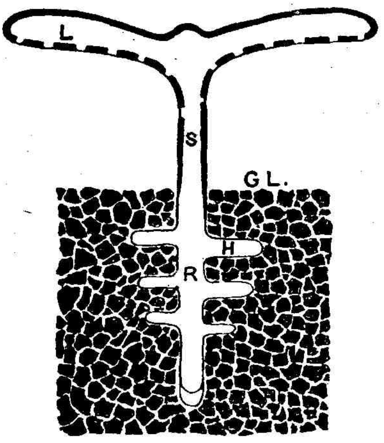


Fig. 8.—Diagram of a Plant in the Soil

The root (R) with its absorbent root hairs (H) is expanded in the soil, the interstices of which are indicated. The stem (S) and leaves (L) are raised aloft. The heavy black edge represents the cuticularized impermeable surface membrane of the shoot. The gaps are the stomata, the points of gaseous interchange. The root system, bordered by a thin line, is water-permeable. *G.L.*, Ground level.

A very important consequence of the intimate relations that obtain between all the ramifications of a root and the soil in which it grows is the firm fixing of the plant in the ground, so that the plant is hardly liable to be uprooted even by the most tempestuous buffeting by wind.

The shoot, on the other hand, is mainly developed above ground, where it displays to the light its green canopy of living cells. It is by the agency of its leaves and other green parts that the plant is able to utilize the CO_2 of the air as its source of carbon; moreover, it is also through the leaves that water vapour is transpired into the air. These functions are carried out under cover of a non-permeable membrane (the cuticle) by special adjustable pores, the stomata, which lead into the interstices of the plant (fig. 8). As these pores can be closed and communications interrupted when necessary there is little fear of a plant drying up.

We see, therefore, that both the root and shoot of a plant are necessarily permeable to water, but that, whilst the root

is protected from desiccation by the soil alone, the surface of the shoot is cuticularized—the pores of interchange (the stomata) being under control. If plants are to be used for coastal or other requirements these fundamental limitations in their mechanism must be respected.

Plants with Permanent Systems.—As these are the most important for coastal work it is convenient to explain the different ways in which plants establish a permanent footing in the ground.

In respect of permanence plants are, roughly speaking, either *annual* or *perennial.* The former, as the name implies, establish each year from seed and endure only for a single season. With the ripening of seed the body dies. Annuals include many "ephemeral" plants on sand dunes and certain pioneer colonizers on muddy foreshores. As will appear in the sequel, they are not without significance to the subject of this book.

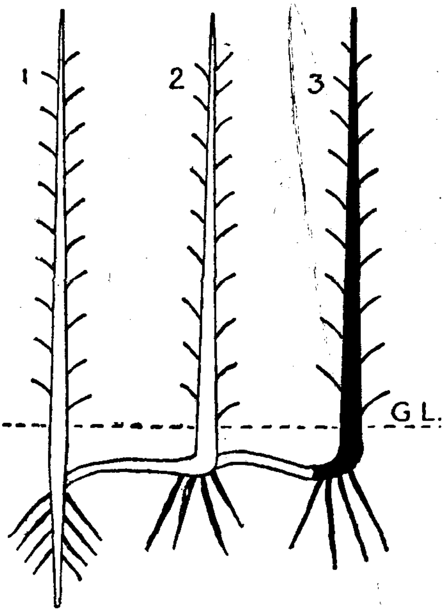


Fig. 9.—Diagram of a Perennial Herb, to show relation of the shoots of successive years to one another. The plant of the third year is drawn solid black. *G.L.*, Ground level.

In some cases vegetative establishment alone is accomplished the first year, flowering and fruiting being postponed to the second season, on which the plant dies. Such plants are termed biennials. On the shore biennials are rare, reputed biennials behaving as perennials.

Perennial Plants.—There are two distinct ways in which and plants perennate:—

(1) That of the perennial herb, the permanent system of which is subterranean;

(2) That of the ligneous plant, which grows into a shrub or tree.

In the *perennial herb* the aerial shoot dies down each year, and the growth is carried on by a lateral bud from the base, which either expands directly to the surface, or (as in fig. 9), first extends horizontally for a variable distance and then bends up to the light. The new shaft thus formed roots freely at the base. Though there is vegetative continuity between the successive annual segments, the body segment of the preceding year is normally abandoned and dies away. The actual plant of any year is thus a rooted branch of last year's plant. To this type belong plants with budding rootstocks, runners, rhizomes, tubers, corms, and bulbs. These are mere variants in detail, depending on food storage and the distance at which the new plant appears above the soil. Most seaside plants are referable to this type.

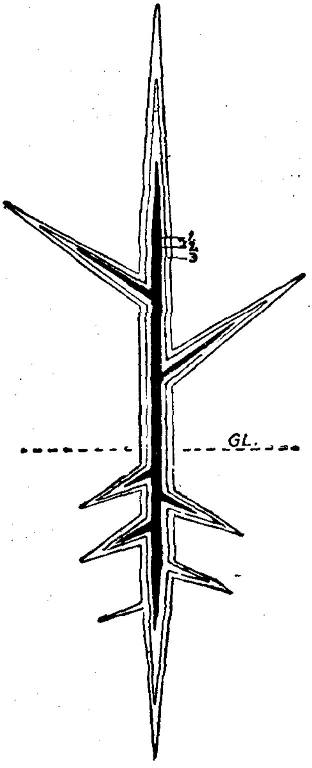


Fig. 10.—Diagrammatic Longitudinal Section of Tree or Shrub, to show relation of the increment of successive years. The black core is the wood of the first year; 2 and 3, of the two subsequent years. *G.L.*, Ground level. The appendages above the line are branches; below, roots.

In the *shrub or tree* the new growth is not carried to a distance, but is added to the original plant in the manner roughly indicated in fig. 10. The growth made each year serves to thicken the original plant and to provide new branches and extensions of the existing ones. Thus from year to year the original plant is elaborated, growing in stature and thickness, till a tree results. The tree remains in one place with annual increase, whilst the perennial herb tends to migrate slowly from its original location, never producing shoots of more than one season's duration.

The above types are characteristic of ordinary fixed or dormant soils, but by the shore soils exhibit mobility, and, as

will appear, this mobility tends to modify the type, imposing even on ligneous plants much of the habit of the perennial herb (cf. Cap. VII).

The Occupation of Ground.—Having sketched in outline certain of the fundamental requirements of the rooted plant, we may proceed to a consideration of the manner in which plants occupy and colonize ground, discriminating between soils which can and which cannot be invaded by plants. Observation shows that whilst some soils are usually vegetated, there are others that remain bare. This sterility depends, of course, upon definite causes, which are not always the same, and which are usually ascertainable.

Now the occupation of ground by plants is a process divisible into two phases—inoculation and establishment.

Inoculation is the bringing of seeds or other transportable germs. In the absence of a parent plant on the area to scatter its seeds, this service is performed by one or other of the three great natural agencies—wind, water, or animals.

In the case of seaside plants water is the most important agent. The tide brings the seeds in their season and leaves them on the drift line, whilst the occasional very high spring tides, by sweeping up the accumulations of lower drift lines, will bring the seeds to the highest levels ever visited by the waters.

Air transport and the feet of birds are minor agencies not to be overlooked. From this it follows that one reason for deferred colonization or lasting sterility of ground near the sea is lack of tidal access.

Establishment.—Whether ground that has been inoculated with seed will become vegetated or not must depend on a variety of circumstances.

1. *Nature of the Surface.*—If this be too hard or compact for penetration by the germinating seedling, an ordinary rooted vegetation cannot establish. At best such ground can be occupied only by such plants as Lichens and Algæ, which adhere to the surface.

2. *Stability.*—Ground may be favourable in all other respects for plant establishment and yet produce no crop in consequence

of too great mobility during the critical period of establishment. As mobility of ground from wave action, tidal flow, or wind is the outstanding feature of all tidal and maritime lands, and is *par excellence* the quality with which the maritime engineer has to contend, the matter evidently demands close attention, especially in its relation to plant establishment.

In most cases mobility of ground takes the form of a displacement of the surface layers under the impact of actively-moving water or air. The phenomenon is essentially a surface phenomenon, and reaches a depth dependent on the violence or duration of the impact. Even an extreme case, such as a storm wave plunging on a beach, merely pares off a surface layer of sand or shingle, and the huge aggregate of material which may be displaced ultimately by a storm is but the cumulative result of these surface parings. Upon this fact depends the principle of stabilizing ground by means of vegetation. It may be this fundamental axiom is sometimes lost sight of when the destructive results alone of a great tempest are contemplated, but it is none the less true.

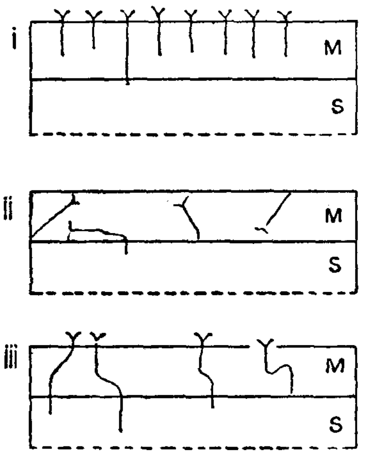


Fig. 11.—Seedlings and Mobile Ground

i, The seedlings before the high tide. ii, After the high tide. iii, Recovery of survivors a week later. M, Mobile zone. S, The top of the stable ground.

The relation of plants in process of establishment to the mobile zone is illustrated by the following example.

On a certain sand-bank not far below high-water mark of the higher spring tides a thin scattering of annual Salicornias (Glasswort) generally establishes. The seeds of these plants germinated in March in the locality under observation, covering the ground with a continuous green mantle (fig. 11, i). In April the spring tides overran the area, turning over the surface layer (about 2 inches), so that nearly all the seedlings were displaced and buried or washed away (fig. 11, ii). During the

following intertidal cycle of stability the seedlings by their further growth and curvature attempted to recover the erect position (fig. 11, iii). Again the bank was washed by a spring tide, and such as had failed to advance their roots into the stable grounds below the mobile zone were upset and buried. The final result was that a very small minority of the seedlings (perhaps 1 in 1000) hung on as established plants, notwithstanding the favourable conditions for inoculation and germination. The determining factor for survival was capacity to reach promptly and take root in the stable soil below the mobile zone.

In the vicissitude just recorded the overwhelming effect of intermittent mobility in the top layer of ground upon seedlings in the act of establishment is clearly shown. But what would have been the consequences if, on another occasion, the seedlings had a few more days in which to lengthen their roots before the spring tide passed over them, so that a very much larger proportion had struck stable ground? The immediate consequence would have been, of course, the survival of a much increased number of plants. But that is not all. In the autumn the Salicornias shed their seed and die. But, as their skeletons remain *in situ* till the following summer before weathering, they would act as a means of stabilizing the ground, thus largely favouring the conditions for the establishment of the next year's crop. This favourable influence they exert in two ways. Their roots remain in the soil, thus helping to bind it together, whilst the dead projecting shoots, by causing a local diminution in the rate of flow of the water, appreciably diminish the depth in the soil to which its effect can reach. The result would be a denser colonization of the area, not for that year only but for succeeding years, till the covering reached maximum density.

It is clear, therefore, that once plants begin to colonize bare ground, the process will rapidly advance till the ground is fully occupied, a result largely due to the cover which the pioneers provide, thereby reducing the mobility of the soil.

Observations of this kind are to be made everywhere, and it is by their right interpretation and application that progress in foreshore control will be made.

To recapitulate: we see that mobile ground becomes stabilized

by an invading vegetation; that where originally no plants could exist a dense covering may be established in a relatively short space of time. Nor is this all. The presence of a vegetation, by retarding the rate of flow of water, will at the same time automatically cause the current to drop its burden of silt which will accumulate about the plants. Thus a covering of plants promotes not only protection of surface (by stabilization) but also accretion, i.e. deposition of silt and rise of level. Here in brief compass is illustrated the mechanical importance of a vegetation on intractable ground, applicable equally to mud, sand, and shingle overrun by the sea, and to the surface of a sand dune unstable in the wind.

Returning to the point from which this section started (p. 49), the actual incidence of mobility has been analysed, and the reason why it may prevent establishment made plain. It is further evident that mobility of soils is intermittent, i.e. endures only for the period during which the mobilizing agency (water, wind) operates. It is clear, therefore, that there are two obvious lines along which the problem of plant establishment may be promoted artificially:—

(1) By lengthening the periods of soil dormancy;
(2) By the selection of plants which establish with unusual celerity.

The problem will be further considered from the practical point of view in later chapters.

3. *Toxic Factors.*—The presence of anything in a soil which acts as a poison, that is to say, which operates in so fundamental a way as to destroy the intimate mechanism of a plant, will prevent plant establishment. In the case of maritime plants the salt of the sea water is the principal agent of this kind. To the great majority of plants existence is not possible in a saline environment. Perhaps 30 species alone (1.5 per cent) of the 2000 flowering plants of the British flora are able to endure immersion in salt water with immunity. The plants of this very select band are drawn from a considerable number of families; they are known as halophytes or salt plants, and constitute the elements of the vegetation of our salt marshes. (See Appendix

IV, p. 267). They are distinguished from ordinary land and fresh-water plants by the high salt concentration of their sap, which enables them physically to hold their own in salt solutions, such as normal sea water (3½ per cent NaCl), or even higher concentrations. It is a singular fact that—apart from the salt marsh—the majority of seashore plants, especially those of shingle beaches and sand dunes, are not halophytes at all, and that if they are covered by an exceptionally high spring tide their tissues are liable to be destroyed and blackened. Nevertheless the apparent recklessness and regardlessness of consequences with which non-halophytes carpet the ground right down to tidal limits are consistently characteristic of vegetation. It is largely conduced by the fact that the ripe seeds of plants of all kinds are almost always impermeable to salt water, and being thus immune are liable to be distributed in good condition wherever the tide carries them. Should the ground on which the seeds are stranded be suitable for establishment it will inevitably be occupied by the seedlings. This is only a single instance of the way in which vegetated areas push their outposts to the extreme available limits.

4. *Attack by Animals.*—This is a factor not to be lost sight of in connection with plant establishment. Thus on waste ground near the sea the influence of rabbit-nibbling is often important enough to prevent a species of plant from flowering even if it does not lead to its extermination locally. The tread of human feet will prevent the establishment of certain plants on or near a path. For this reason a track over a heath is bare of Calluna, or a field path of thistles. Constant footsteps tend to eradicate certain plants from grassy turf without injuring the turf itself. That the factor is liable to operate differentially, and that it is not always easy of detection, will be sufficiently obvious.

5. *Availability of Plant Food.*—The last of the factors upon which plant establishment depends is the availability of the raw materials of a proper nutrition. Wind-blown sand from the foreshore and pure shingle, for example, as they accumulate to form dunes and beaches are inhospitable media. The soluble salts indispensable to a plant are available in new soils often

in the smallest quantities, and their absence would present a serious obstacle to plant establishment were not some other source available. In practice this is supplied by the dead remains of pre-existing plants, which become embedded in these soils and serve as manure for future generations. The tides and currents form an elaborate agency for the collection and distribution of this manure, which consists of seaweeds, and of the leaves, twigs, &c., of the plants of the salt marshes, which, together with other organic flotsam and jetsam, are swept up in enormous quantities, and left on the drift line high up on the beach. As the beach consists largely of mobile matter, an adequate mingling of organic drift and beach materials is ensured by the same agency. The mud flats regularly overrun by the tides are occupied by special mud algæ, which become bedded in and form the basis on which is raised the salt marsh proper, whilst sand dunes, which at their inception rest on tidal beaches or marshes, derive their initial humus in the same way. Once a vegetation starts on any of these formations it becomes self-supporting, utilizing the materials of the vegetations that have gone before. This stored plant food or humus is of just as much importance for the support of a vegetation on these mobile maritime soils as is the humus of the forest floor inland. The matter will be dealt with in its special aspects in the chapters which follow. It is referred to here on account of its fundamental significance in connection with any attempt to cultivate plants for particular purposes on maritime soils.

The Mechanical Value of Plants.—Before concluding this very general sketch of some of the main characteristics of plant growth, and the bearing of the salient factors of the shore upon the establishment of a vegetation, a brief introductory statement is required of those special qualities of plants which lend themselves to the purposes of the maritime engineer. Apart from harbour construction, the services of maritime engineers are required for the achievement of two principal ends:

(1) The preservation of existing land surfaces from encroachment by the sea;

(2) The extension of land surfaces by reclamation.

For the purpose of protection (alone illustrated here) two methods are employed. There is the direct method of facing the raw edge of the land with a sea-wall of timber, masonry, or the like, so that the tides and waves are denied access to the erosable surface; and in addition to this, there is the more important indirect method, by which the travel of mobile beach material along a foreshore is arrested by the construction of groynes. These groynes are in essence low fences projecting from the shore, and extending from extreme high-water mark beyond extreme low-water mark. Groynes are built of timber, reinforced concrete, or other materials appropriate to the exposure and force of the waves. In this way the foreshore is subdivided into compartments or embayments, open in the seaward direction, and these compartments have the object of raising the height of the beach, by trapping shingle and other beach materials in transit.

When this object is realized the sea no longer reaches the mainland, as the high-water line has been pushed out an appreciable distance from the shore.

One of the intentions of the present book is to consider if and to what extent the constructions of the engineer may be supplemented, modified, or even replaced by the employment of vegetation suitable to the purposes in view. The qualities of plants which seem to render them useful in this connection are:

(1) Their capacity to reduce the mobility of terrain: (*a*) by penetrating it with their roots and rhizomes; (*b*) by the shelter which their projecting parts afford to the surface.

(2) Their capacity to accrete matter and hold it in place, at the same time growing through and occupying this new stratum of accreted matter, so that their action is continuous and automatic.

For over a century vegetation methods have been employed with increasing success for the fixing and reclaiming of sand dunes. Consequently we shall deal first with the sand dune, and then proceed to cases of muddy foreshores and shingle

beaches. Throughout, our method will be to study precisely the relation of vegetation to these various terrains under perfectly natural conditions, where there has been no interference by man. It will then be possible to see in what ways and to what extent the natural mechanism may be applied and extended in the service of maritime engineering.

CHAPTER V

Sand Dunes

Whilst the term Dune is applied generally to hills or other topographical features of which the materials have been assembled by the winds, and which are still, or were till a comparatively recent period, subject to modification of relief by the same agency, consideration will here be restricted to dunes composed of sand, and in the main to those of the littoral zone. If the estimate by a competent authority be accepted that as much as seven per cent of the earth's surface is dune-encumbered, it is evident that the coastal sand dunes can form but a fraction of the whole area. Though not strictly coming within the category of "tidal lands", the sand dunes of the shore naturally fall within the subject of this book. They abut on and delimit many tidal lands, and are important in relation to defence from the sea. Moreover, as they readily lend themselves to stabilization and reclamation by planting—in connection with which a highly elaborate technique has sprung up—it is evident that the subject must receive the attention of the maritime engineer.

In effect, the sand dune is reproduced in miniature in the ripple marks of every seashore, and it can be simulated by the action of the sand blast. If the particles of sand on a shore were all exactly the same size and weight, no ripple marks would be produced. These are due to slight variations in the weight of sand grains which are whirled into suspension by the wind and heaped up by reflex action. The wind, flowing in lines parallel to the surface, on passing the crest of any irregularity or obstruction sets up a return eddy, lifting the lighter particles to the top of the ridge so produced. Its action is

similar to that of winnowing. As an examination of sand ripples demonstrates, their windward slope is always flat, their leeward slope acute. Wherever a wide stretch of sandy foreshore is exposed and some slight obstruction to the travel of blown sand exists, the familiar phenomenon of the sand dune is reproduced.

It will be obvious that whenever an elevation or depression of a sandy coast-line takes place such condition is ripe for the formation of sand dunes. Holland is a case in point, and the sub-Glacial strata of that country bears witness to the fact.[1] The Pliocene strata of Holland rest in a shallow basin rising towards Norfolk, Germany, and Belgium. The depression of the Dutch area was contemporaneous with a rise of 500 to 600 feet in the Pliocene sea bed along the coasts of southern England and north-western France. The prevailing winds being then, as now, westerly, these movements probably furnished the origin of the sand barriers along the coast-line from the Seine to the north of Holland.

Along the English coast sand dunes pass under a variety of names, such as the Denes at Lowestoft, and the Meals or Meols of Lancashire and Cheshire; in Cornwall they are termed Towans, and in Devonshire, Burrows. In addition to the above, other dune systems are to be found in Norfolk, Somerset, Cumberland, and the east coast of Scotland. Both in area and *in height the British dunes are inferior to those of the* N.W. coast-line of Europe, where they prevail from Spain to Riga. Of these, the most extensive system is that of Gascony (150 miles long, 2 to 5 miles wide), on the Atlantic seaboard of France; whilst others occur S.W. of Boulogne at Le Touquet, along the coasts of Belgium, Holland, and Denmark, and the Baltic littoral of Prussia. Here, on the Kurische Nehrung they exceed 180 feet in height (at Pillkoppen), whilst the dunes of Gascony have approximately the same height, except at Biscarosse, where they reach 250 feet or more. Scolt Head in Norfolk, about 60 feet high, is typical of the British dunes (Plate IV, 1). Greater heights are attributed to the dunes of

[1] "The Pliocene Deposits of Holland and their Relation to the English and Belgian Crags" (F. W. Harmer), *Quarterly Journal of the Geological Society*, Vol. LV, p. 748.

The Scolt Head Dune Massive from the West—seen over a Creek and Statice Marsh
(Burnham System, Norfolk)

Young Dunes arising on the Shore; Older Dune Ranges to left of Bare Inlet
(Blakeney Point)

Tunis, Tripoli (600 feet), Madagascar (400 feet), and the south coast of Australia (300 feet), but these figures need corroboration.

In the desert Pampas of Peru the familiar phenomenon of sand dunes is in evidence. Alongside the railway, inland of Arequipa, the dunes form in serried sequence. They follow the normal horned shape, and in some cases the space between the horns is about 50 yards. The railway track rises about 1 in 100, and the dunes march correspondingly uphill. This rate of march is stated to be about 100 yards per annum. When they reach the hills flanking the desert the sand slope becomes too steep to permit of their further advance. The notable feature in connection with the dunes of this district is the ingenious and simple method by which they are dispersed when threatening to overwhelm the railway. Loose pebbles and grit from the surface of the pampa are scattered in a thin layer over the rear flank of the dune, the result being that ripple action is stayed. The dune assumes an irregular contour, and this affords the wind an opportunity of penetrating through the mass of it and scattering its constituents. The process of disintegration is stated to be fairly rapid, and, when complete, nothing remains but the grit and pebbles lying on the surface of the pampa.[1]

The materials for the dunes with which we are concerned are brought by onshore winds from the foreshore. At low tide on sandy shores the top layers of sand become dry and incoherent, and constitute the reserve or depot from which the dunes are built up. The grains of sand are swept along by the wind, the movement being in nature largely a rolling or hopping of the particles from point to point. Where obstacles or inequalities of the ground are encountered, the wind is deflected and the transported sand comes to rest in the tranquil places on the lee side of the obstacles.

In this way miniature sand dunes arise on the lee sides of bunches of drifted seaweed on the tide-mark or of growing plants. The further growth of such dunes is determined by the

[1] "Sand Dunes in the Peruvian Desert" (W. S. Barclay), *Geographical Journal*, Vol. XLIX, No. 1.

amount of shelter which the obstacle provides. When this shelter is satisfied no further expansion will take place, as there will be equilibrium between the amounts of sand brought and removed by the wind. A brushwood fence planted in a sand-laden windway will collect a bank of sand not exceeding the height of the fence. On the other hand, a living plant which continually grows up through and projects beyond the sand heap which it collects will raise a dune of considerable proportions. This result, observable on any system of sand dunes, was very concisely described by the late Sir Francis Galton in speaking of the 'Nara, a prickly gourd (Acanthosicyos) at Walfisch Bay. "It (the 'Nara) is a very useful agent towards fixing the sands; for as fresh sand blows over and covers the plant, it continually pushes on its runners up to the air, until a large hillock is formed, half of the plant, half of sand."[1]

This is the essential principle on which primary dune systems arise. For simplicity, the case may now be considered of dunes arising on a growing coast-line, i.e. a shore advancing seawards by the accretion of successive terraces of shingle or sand which reach above high-water mark. Grasses, such as Marram (*Psamma arenaria*) and *Triticum pungens*, or the Sea Sandwort (*Arenaria peploides*), arise directly upon the shingle from seed left in the tidal drift, and around these sand collects to form embryo dunes (Pl. VIII, 1, p. 84). The plants push through to the surface and more sand is collected, and the little dunes grow in height. Some plants (Triticum and *Arenaria peploides*) have quite limited powers of vertical extension, and unless some other species comes to their aid such dunes will remain dwarf, but Psamma is endowed with capacity for indefinite growth, growing vertically and spreading horizontally (fig. 12). In this way the embryo dunes expand both vertically and laterally till they coalesce into dune systems, and the growth continues till the dune systems form ranges of Psamma-covered sand-hills. The rate of expansion depends largely on the amount of sand blown up from the foreshore—a vertical rise of a foot a year being of normal occurrence. As the Psamma never forms a close turfy covering, the bare surface remaining

[1] F. Galton, *The Narrative of an Explorer in Tropical South Africa*, p. 22. 1853.

visible between the tufts, sand is both removed from the dunes in this phase as well as deposited. As, however, the amount retained exceeds that blown away, the sand-hills continue their growth. But if, as commonly happens, on the type of shore under consideration, another bank of shingle or sand is thrown up on the seaward side of the one first formed, this may undergo colonization by plants, and another, outer, system of dunes will arise. Such a system intercepts much of the sand supplies that fed the older systems, with the result that the first range will grow no more in height, and may, on the contrary, be lowered by loss of sand which is not replaced. Where sand supplies entirely fail, dune systems gradually shrink, unless the surface be covered by a perfect carpet of secondary colonists. Even then, though it may be deferred for centuries, the fate of a dune starved of sand is to be lowered to base level, because rabbits are continually burrowing and exposing the bare sand to the wind.

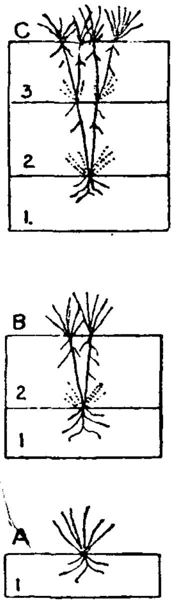


Fig. 12. — Diagrams showing Relation of Psamma to an Intermittently Rising Ground Level

A, Plant growing in the original soil (1). B, A second stratum of soil (2) having been deposited, buds push up to the new surface, where tufts of leaves are formed. Roots arise from these rhizomes and the original tuft of leaves dies (dotted). C, Shows the further history after addition of a third layer of soil (3). The dotted structures are the dead leaves. (After Massart.)

The type of dune building just outlined tends to produce successive ranges of more or less parallel hills (Plate IV, 2). The dune, in many quarters of the earth's surface, is an effective barrier of defence against sea encroachment. Egypt would probably have been blotted from the map and the fertile Nile Valley obliterated, as has happened over large tracts abutting on the Persian Gulf, had the sand drifting up from the Desert not been arrested by vegetation and protecting sand-hills thus brought into being. These primary ridges, however, become modified and distorted by the play of conflicting winds, so that the prevailing relief is very complicated and defies analysis.

As a rule, in passing landwards from the shore, dunes become less mobile, and with the decline of mobility of surface many additional species of plant are able to establish, till the surface becomes closed over by vegetation. In this condition dunes become relatively stable, though, of course, the constant action of rabbits tends to reopen them.

Mobile dunes are mainly characterized by Psamma, though as an alternative, especially on the East Coast, the Lyme Grass (*Elymus arenarius*) is frequently met with. Other plants proper to mobile dunes are the Sea Holly (*Eryngium maritimum*), the Sea Spurge (*Euphorbia Paralias*), the Sea Sedge (*Carex arenaria*, Plate V), and, along the drift line on the seaward face, the Saltwort (*Salsola Kali*) and Sea Rocket (*Cakile maritima*). These two plants of the strand edge being annuals, have little value as dune builders. They are, however, in the absence of other *débris*, a reliable guide to the position of the highest drift lines.

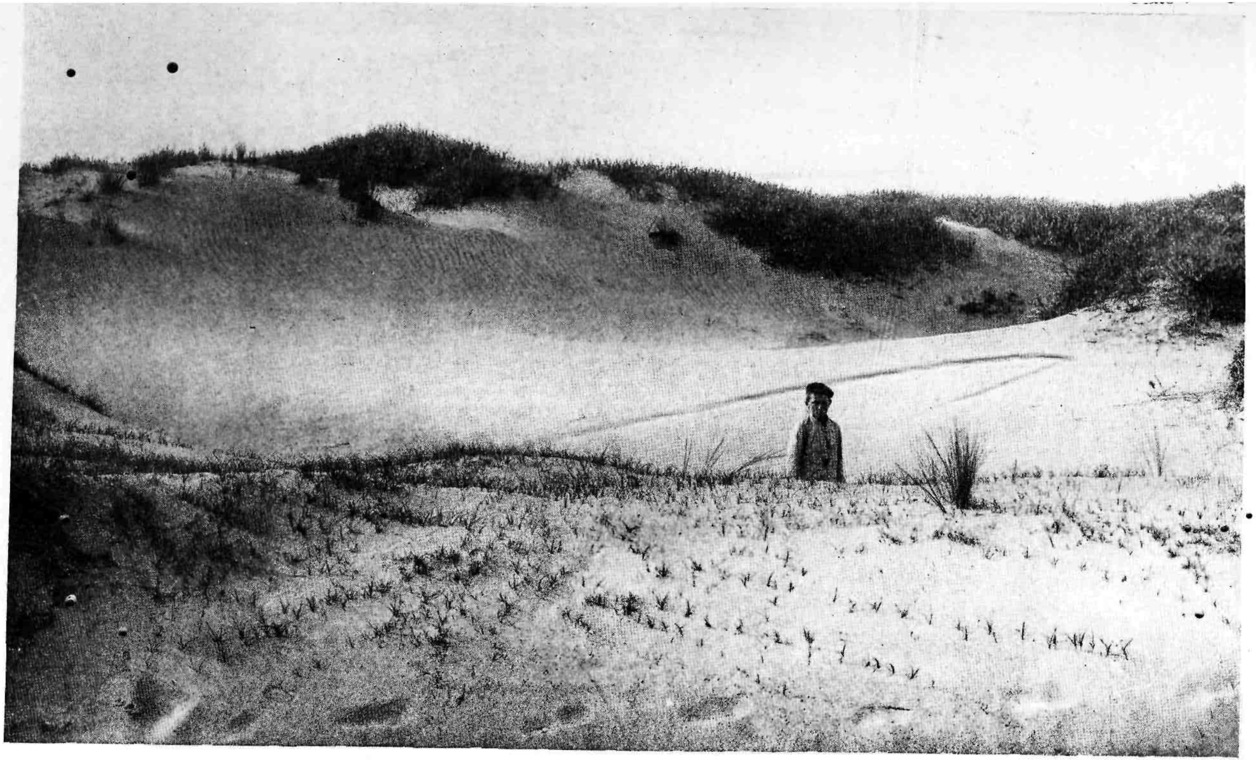
On the more stable dunes other plants come in and complete the fixing process. These are very numerous, and include the Storksbill (*Erodium cicutarium*), Stonecrop (*Sedum acre*), Bird's Foot Trefoil (*Lotus corniculatus*), Ragwort (*Senecio Jacobæa*), Lady's Bedstraw (*Galium verum*), Thyme (*Thymus Serpyllum*), and many others. (See Appendix I, p. 263.)

Very important as sand fixers are the lichens *Peltigera canina* and species of Cladonia, which include the Reindeer "Moss", Cup "Moss", &c. It is the presence of this element that has gained for the fixed dune the name of "grey dune" in contradistinction to the "white dune".

Some mosses, such as *Tortula ruraliformis* and *Ceratodon purpureus*, sometimes form continuous sheets on old dunes and have a corresponding mechanical value.

A certain number of bushes are to be found on dunes. The following is a list of shrubs occurring on the Scolt Head system (Norfolk). It is interesting to note that the fruit in each case is fleshy, thus indicating introduction by birds.

Elder,	Gooseberry,	Blackberry,
Privet,	Dog Rose,	Hawthorn.



Photo, J. Massart

DUNES COLONIZED BY *CAREX ARENARIA* AND *SALIX REPENS*. COXYDE, BELGIUM

Another characteristic dune shrub is the Sea Buckthorn (*Hippophæ Rhamnoides*), also in possession of succulent fruits.

Dune plants as a whole tend to be deep-rooted, partly by rapid downward penetration at establishment — doubtless a response to the necessity of laying under contribution the moister layers of sand — partly from the piling up of sand brought by the wind. So extensive are their root systems that it is practically impossible in the ordinary way to dig up any of these plants intact. Only when a dune cliff is undercut by a high tide and falls in masses can plants with their subterranean systems entire be recovered from the *débris*. Practically any dune hill is penetrated everywhere, from base to summit, by roots and rhizomes.

An exception to these statements is afforded by the "ephemerals", plants which arise from seed each year, germinating in the autumn or winter, flowering in March and April, and ripening their seed before the summer. These, unlike the perennials, are shallow rooters, and depend for their water supplies on surface moisture. In early spring the dunes are often gay with ephemerals, such as Whitlow Grass (*Draba verna*), Rose-leaved Saxifrage (*Saxifraga tridactylites*), Mouse-ear Chickweed (*Cerastium semidecandrum*), Early Forget-me-not (*Myosotis collina*), and others of like habit. Though present only for a limited time, these ephemerals play their part in helping to screen the soil, especially at a season when much of the other vegetation is still dormant. Furthermore, at their death their remains contribute humus to the dune soil.

With the complete stabilization of a dune Psamma and other pioneers lose their primeval vigour, cease to flower, and fall into a mangy-looking state. Sooner or later they die out, and the passage of the dune from the primary white phase to the grey secondary is complete. Dune pioneers flourish luxuriantly only so long as the sand about them is mobile. Under these conditions their green is of a deeper hue, and flowering spikes are freely produced. Whether the soil becomes depleted of an essential component, or whether the covering of the surface by other plants interferes with the aeration of the Psamma roots and rhizomes, or finally, whether deleterious secretion-products

accumulate in the stagnant soil which automatically render the ground unsuited for Psamma to flourish, has not been determined. Be this as it may, the dune pioneers illustrate a general property of plants, viz., that after the lapse of a certain period they grow soil-weary and are replaced by another vegetation phase. The underlying causes here are probably the same as those which determine the necessity for the agricultural operation known as rotation of crops.

Whilst the preceding account may serve to illustrate the general phenomena of dune building, it will be understood that even on an advancing coast-line a spontaneous vegetation may not arise fast enough to fix the sand blown in from the shore. In point of fact it rarely happens in wild, unregulated dunes that there is equilibrium between the sand supplied and the capacity of the natural vegetation to fix it. Commonly such a dune area retains a high degree of mobility, and where the system is extensive, as on the Biscay littoral and the Prussian Baltic coast, artificial methods of dune control have been developed.

In view of the interest of these methods and their comparative neglect in this country, a short description of them will be given in the next chapter of this book.

Whilst the dune systems of Gascony, Southport, and Blakeney Point (Norfolk) occupy coast-lines which have in recent times advanced seawards owing to the accumulation of materials, this is by no means always the case. Some coast-lines are stationary, whilst others—perhaps the majority—are in retreat.

The existence of parallel ranges of dunes is generally an indication that the coast-line was advancing, at any rate, during the period at which the system was laid down, i.e. that new ground became available between existing ranges and the sea to carry the ranges of more recent date. From the nature of the case such ranges do not attain very great heights, since the intercalation of each new range is equivalent to the placing of an additional screen between the older ranges and the source of sand supply.

With a stationary coast-line, as on the Kurische Nehrung

and Frische Nehrung of the Prussian Baltic, the available sand is continually or intermittently added to one and the same dune range, which thus exhibits an almost unlimited capacity of growth, and reaches a height of 150–180 feet. When in such cases vegetation is absent, or inadequate to bind the supplies of sand, the dunes "wander" and overwhelm the adjacent land surfaces and villages. It is phenomena of this kind exhibited on the grand scale that have compelled attention to methods of artificial dune fixation.

Where the coast-line is in retreat, i.e. undergoing erosion at the hands of the sea, the dunes which encumber it will not be left behind. The edge of the dunes, equally with the land platform on which they rest, will undergo erosion, but the sand will be thrown up on the foreshore and blown once more on to the land and reconstituted. The dune fringe consequently accompanies the land in its retreat. Such coasts, which are very common, are distinguished by the presence of a steep cliff face overlooking the sea.

Though we have for convenience distinguished between the dunes of these different types of coast, it will be understood that the phase of a coast-line is continually changing; that which was stationary a few centuries ago may now be advancing seawards, for instance. This circumstance accounts for the existence on certain coasts of dune systems not in harmony with the present phase of movement of the coast-line.

The Wandering of Dunes.—Wherever accumulations of sand are laid bare, as by natural or artificial disafforestation, or where rabbits or storms break through the covered surface, causing injuries rapidly extended by the wind, dunes are liable to travel, i.e. to be transported in the direction of the prevalent wind, overwhelming everything they encounter. This state of travel or wandering is normal with dunes on desert areas where the conditions of drought, combined with the mobility of the sand, make the establishment of a vegetation uncertain or impossible.

Such wandering dunes may be quite bare, or they may carry clumps of Psamma dotted about, but inadequate to retard materially their progress. Under these circumstances the sand

is blown up the windward slopes to the crest and over the crest, where it falls in an ever-advancing talus on the lee side, lying at the critical angle of repose for loose sand—about 30 degrees. Plate VI, the upper picture, shows a wandering dune at Le Touquet invading a dune valley. A willow, *Salix repens*, is growing through and occupying the advancing sand.

In this way the dune ranges on the Kurische Nehrung have been advancing yearly some 18 to 20 feet for a considerable period, burying farms, villages, and cultivated land in their progress. It appears that in the Swedish war of 1657 the Prussians themselves were compelled, as a measure of military precaution, to disafforest a considerable stretch of these dunes,[1] whilst later disafforestations occurred in the eighteenth century, though whether at the hands of the Russian troops in the Seven Years' War or from accidental fires is uncertain. In the case of the Gascony dunes the mean rate of advance was about 30 feet a year, though on certain occasions at particular places 70 to 80 feet have been recorded. If in Britain the consequences of neglect to stabilize our dunes are by comparison trivial, it is because the areas involved are relatively small. A well-authenticated case occurred in Cornwall at Peranzabuloe, near Truro, where the church of St. Piran, overwhelmed in the eighth or ninth century, emerged from the sand once more in the year 1835; another is the Culbin Sands in Elgin.

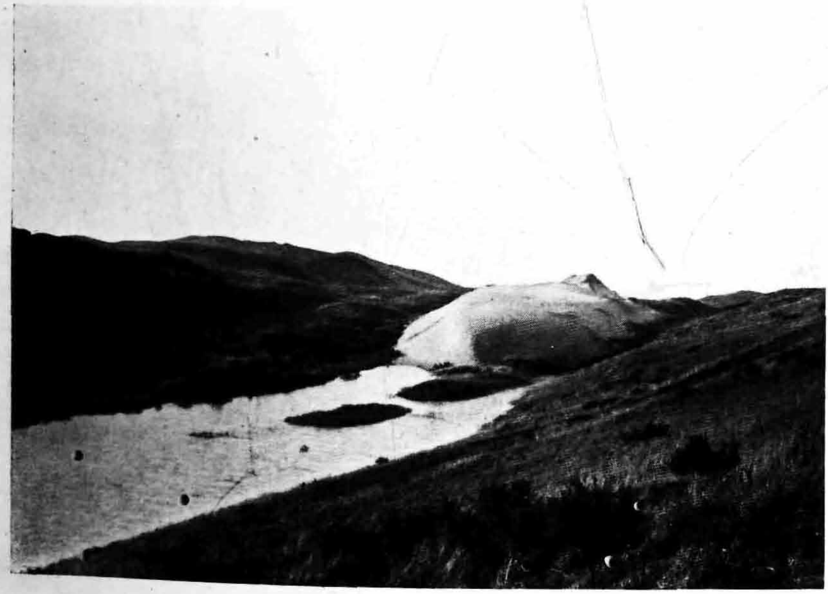
In a smaller way in quite recent times the reopening by the wind of a system of covered dunes in Jersey, in the Bay of St. Ouen, north of the Corbière Rocks, may be mentioned. Here the drifting sand has advanced some distance up a small valley, the obstruction causing a lake to collect. At the worst only a small area of pasture land has been flooded; the example is cited because the phenomena of wandering sand, cause and effect, can be studied here in compact compass (Plate VI, 2).

On the North Wales coast definite records exist of recent movements of sand dunes.

West of Prestatyn, North Wales, sand dunes rise to a height of nearly 100 feet, and a wide plateau of sand stretches on their

[1] Voss, in *Zeitschr. f. Allgem. Erdkunde*, N.F., 11 Bd., Berlin, 1861, p. 251.

Le Touquet; Sand overwhelming a Dune Valley, *Salix repens* growing through



On the Quenvais, St. Ouen's Bay, Jersey

WANDERING DUNES

seaward side. The following residues show the fineness of this sand, which is typical dune sand:—

Residue on 50 × 50-mesh sieve	1.0
Through 50- and caught on 76-mesh sieve	44.0
Through 76-mesh sieve	55.0
	100.0

The shape of sand particles affords an index of their mechanical history. It has been inferred from experiment that completely to round a grain of quartz sand $\frac{1}{50}$th of an inch in diameter the coincident abrasion must be equal to that of a travel of 3000 miles. The fact of quartz sand being found polished and rounded is, in the vast majority of cases, evidence that it is æolian sand, and that the action of grinding down its sharp angles and reducing it to the condition of a smooth pebble in miniature has been caused by the sand having been blown backwards and forwards under the impulsion of wind. Small pebbles and gravel under attrition, due to current or wave travel, tend by slow degrees to become smooth and spherical, and this action goes on to considerable ocean depths. The slow grinding of the sea forces is in effect similar to the action of the tube mill, in which the material to be reduced to powder is revolved in a cylinder laden with large flint boulders, until the product is pulverized to the fineness of flour. The late Mr. W. Pengelly, F.R.S., has left on record the fact that a jar sunk in 36 fathoms of water became partly filled with sand and gravel, thus proving the existence of motion in deep-sea deposits under the impetus of tidal current and that of wind pressure induced by gales. Such action below low water is intermittent and slow, whereas there are few days in the year when there is not sufficient wind to set in motion the superficial sand of an exposed coast-line and cause its attrition.

Recent observations in Egypt have demonstrated the fact that the sand of the desert blown from the surface of dunes is heavily charged with positive electricity. Moreover, the canopy of air over the Libyan Desert shows about 50 per cent more ozone in comparison with that of the oases. The local physical perturbations thus indicated may afford the key to the phenomenon

of excessive rainfall over dune areas in Northern Europe. As the velocity of wind blowing over dunes increases, its relative sand-transporting power advances rapidly in a progressive ratio.[1]

Immediately east of the town of Rhyl dunes are in regular course of formation (fig. 13). In 1899 portions of the dunes then forming were levelled, but they have sprung up again, and are a continual source of expense to the town. Between 1901 and 1905 this expenditure averaged £176 per annum; during the next four years it increased to £277 per annum, and has since remained at about this figure.[2] The expedient hitherto adopted has been that of removal of the sand from the land side of the dunes. The constant encroachment of the drifting sand is a serious nuisance, apart from the expense of its removal.

A characteristic form often assumed by wandering dunes is the crescent dune or "barchan". In this the concave side of the crescent lies to leeward, the sand is blown up the convex windward face, and falls into the interior of the half-crater as a steep talus. The horns are directed forward because they travel faster than the main body of the dune in consequence of their lower altitude. Barchans are particularly well shown by desert dunes. Indeed, the freaks played by the travel of sand in Arabia are almost incredible. Mr. W. S. Blunt took the measurement of some of the desert "fuljes". These resemble gigantic pits sunk below the level of the sandy plain. They are horseshoe-shaped excavations, having a maximum depth of 280 feet, rising up to and above the level of the desert in a flat gradient. A shift of wind may quickly obliterate them or cause them to forge ahead.[3]

It is a curious fact that records of the wandering of dunes in Europe are for the most part modern, though the phenomenon of wandering, had it been known to them, must have been described by ancient writers. In New Zealand, also, in the early

[1] "The Nature and Formation of Sand Ripples and Dunes" (W. J. Harding Cox), *Geographical Journal*, Vol. XLVIII, p. 207.

[2] Data furnished by Mr. A. A. Goodall, engineer to the Rhyl U.D.C.

[3] For a detailed study of the movements of blown sand, including many of the phenomena of desert dunes, the reader is referred to Vaughan Cornish's *Waves of Sand and Snow* (Fisher Unwin, 1914).

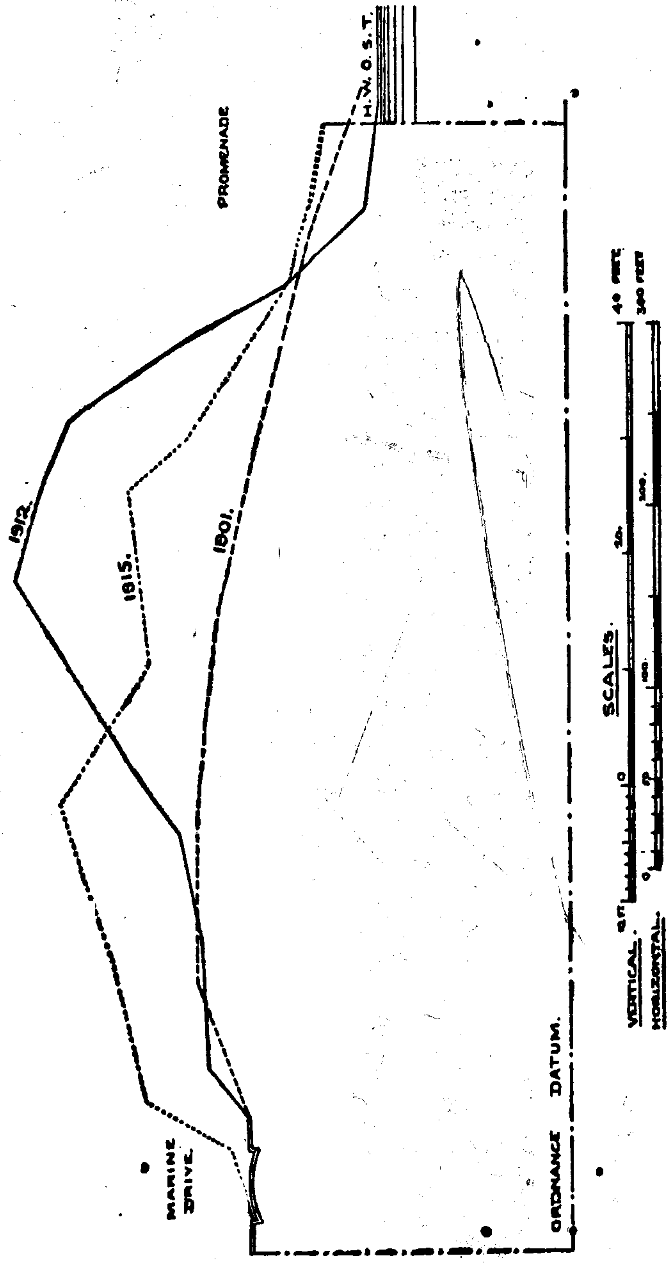


Fig. 13.—Section of Sand Dune Formation, Rhyl

days of settlement, the dunes were quite generally carpeted by vegetation, not drifting as they are to-day. The inference is that, unless we have entered a new geologic era so far as dunes are concerned, wandering is a result of man's own negligence. However this may be, the phenomenon more than a century ago asserted itself as an economic problem of the first magnitude on the shores of Continental Europe, and its solution has been reached by systematic and continuous study directed by appropriate State-organized departments. In the next chapter we give an account of the methods of dune fixation that have been reached, especially in connection with the Biscay and Baltic littorals.

CHAPTER VI

The Fixation and Plant Protection of Sand Dunes

The technique of sand-dune fixation, like all other arts, evolved slowly. The impulse to do something must have been irresistible when dune systems broke their bounds and wandered impartially over habitations and cultivated ground, bringing disturbance or ruin in their wake. Pressure was put on the authorities, and a move made towards ameliorating the conditions both in Gascony and the Prussian Baltic in the latter part of the eighteenth century.

At first the expedient was tried of erecting fences along the crests of the high wandering dunes with a view to retarding their progress, but this was found to heighten the crest with eventual aggravation of the trouble.

It must have been perfectly obvious to anybody who considered the matter that relief from this plague of drifting sand was to be got only by a covering of vegetation; but the selection of the right plants to use and the tactics to be employed to ensure their establishment on highly mobile ground could only be determined by comparing the results of numerous experiments.

It is not possible here to follow historically the gradual development of current methods, or to consider in detail the treatment found most appropriate for types of dune systems differing from one another topographically and in the incidence of mobility. All that can be done is to deal with the general principles.

Littoral and Inland Dunes.—In most cases of extensive dune systems the supplies of sand originate at the shore, and

are drifted inland by the wind; the inland dunes are largely bare, and hence inherently mobile; they also receive constant additions from the shore. Hence the general problem of fixation resolves itself into two distinct problems which are quite different in nature. In the first place, the sand from the shore must be

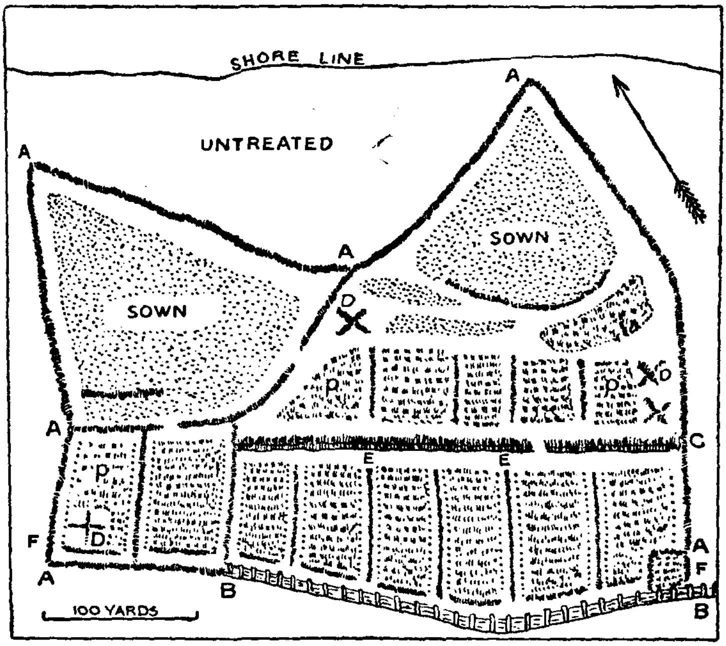


Fig. 14.—Chart of an Early Experimental Dune Planting by Sören Biörn (1795)

The area shown covers roughly a quarter of a mile and slopes up from the shore. It is delimited by the brushwood fence AA. At BB is a planked paling which would perhaps form the crest of the new dune. At C is a high hurdling of Alder. The fences of the F series are low brushwood, whilst those of the E series are of living Poplar, with *Salix repens* on either side (the dotted vertical lines). At DD are depressions occupied by brushwood fences placed crosswise. The larger areas at the top of the map were sown with Psamma seed (dotted), whilst the rectangular areas (some marked P) were planted with cuttings of the same (after Gerhardt).

prevented from adding itself to the inland dunes; it must be collected and fixed near the shore line in what is known as a *littoral dune*. The interior wandering dunes must be dealt with separately. Being no longer liable to accretion from the sea, it is simply a question of preventing their movement. The two parts of the whole phenomenon are therefore dealt with as

distinct special phenomena, just as in modern warfare with entrenched lines there is the attack on the first line of trenches and at the same time the artillery barrage directed beyond to prevent the enemy bringing up reserves from behind.

We may now deal separately with these two regions—the littoral dune and the wandering dunes behind the same.

The Littoral Dune.—Quite early in the history of the art of dune fixation it was realized that a marginal belt to catch the sand as it blew up from the shore was a necessary preliminary to the planting of the ground farther from the sea. Nor did it suffice merely to maintain with a grass covering the existing marginal zone of the wild dunes, on account of the difficulties occasioned by the irregularities of its seaward edge. These included both difficulties of upkeep and liability of the dunes to local encroachment and destruction by the sea.

The ideal littoral dune should run on large lines following the general trend of the coast rather than its minor irregularities; it should also be far enough from tide-marks to be out of danger of wave erosion; finally, its crest should run fairly level and not reach too great a height.

A broad, low littoral dune will hold at least as much sand as a high narrow one, and is much easier to maintain. The littoral dunes in Gascony (45–60 feet above high-water mark) are admittedly too high; 20–30 feet, as on the North Sea and Baltic, has been found much more convenient.

In the case of the littoral dune it is a new structure that has to be built up, i.e. arrangements are made for the trapping of sand as it blows, and for the distribution and retention of this sand on the dune thus arising, so that a proper profile or section may be maintained at every stage. The littoral dune is not required for any ulterior object; it is a trap to catch and hold the sand so that it shall not drift beyond the desired limits. The device employed must therefore operate permanently.

With the wandering dune it is different. Here, once a littoral dune has been called into being, it is mainly a matter of preventing the movement of sand till such time as trees planted under shelter become capable of screening and holding the ground by themselves.

The general method of procedure is to erect two brushwood fences parallel to the shore, from 20–100 yards distant therefrom (fig. 15, A). These fences soon collect a bank of sand, and when they are buried two more fences are placed above them (fig. 15, profiles B, C). When these in their turn have been buried the resulting bank of sand is planted with Psamma (D, E). The fences determine the position of the crest; all further catching of sand and growth of the dune is carried out by the Psamma alone.

It is generally possible to plant the dune with Psamma by the end of the first or beginning of the second year. By the end of the second year a functional littoral dune should be in existence. Great importance attaches to the form of the profile or section of the dune; the slope up from the shore must be at a gentle angle and quite uniform, the crest broad and flat. The equal growth of the slope is determined by the density of planting, the spacing of the Psamma being more open towards the shore and closer as the crest is approached (for stages see fig. 15, E, F, G). By this device the natural tendency of the foot of the slope to hump is eliminated. Local irregularities are corrected by removal of Psamma; the wind does the rest.

The upkeep of the littoral dune is of the first importance; injuries to its surface from storms, rabbits, or other causes must be repaired at once by the planting of Psamma. When a littoral dune grows so high that its maintenance becomes difficult it is probably time to see about the building of a new one on the seaward side.

The littoral dune is thus an artificial product, designed and regulated by man with the aid of plants and the play of physical forces. It is one of the objects of this book to draw attention to this inherent plasticity of all tidal lands (sand, shingle, mud), so that with further study the possibility of far-reaching control in their relief may be attained. The relief of tidal lands differs from that of the mainland, in that it depends primarily on the circumstances under which the unit particles are assembled. The relief of the mainland, on the other hand, is determined by the agents of erosion; it is what survives when these agents have taken their toll. The difference is comparable to that

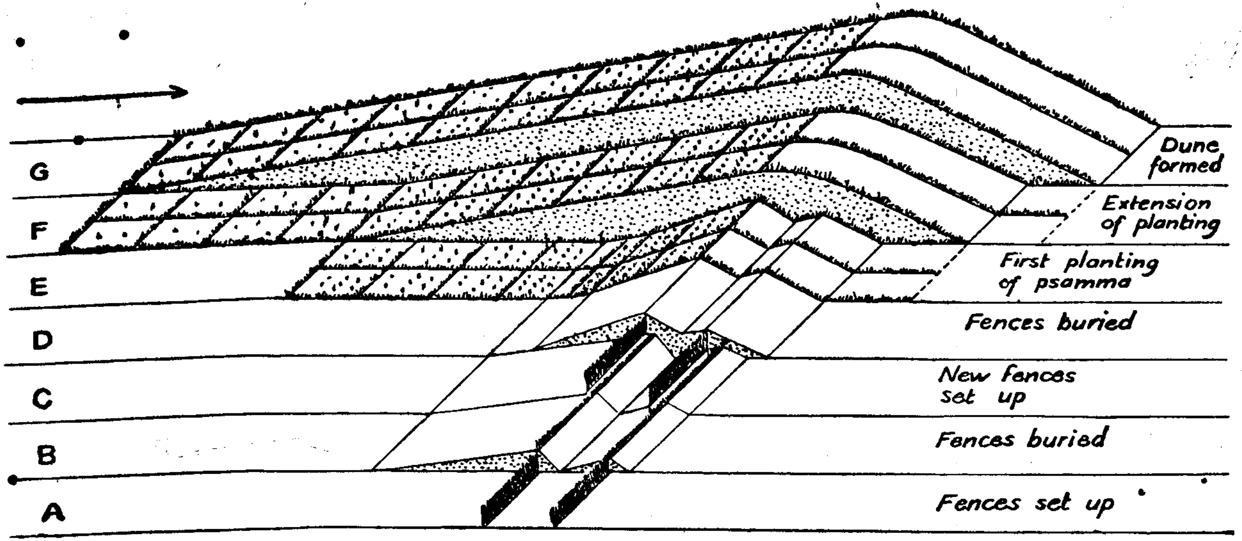


Fig. 15.—Diagram showing Seven Stages (A–G) in the Creation of a New Littoral Dune

At A two brushwood fences are erected 2 metres apart in early spring. They are sanded over in a few weeks (B), and a second tier of fences is placed above them (C). By the end of the summer (D) these also are sanded over. The final planting of Psamma is carried out in the autumn of the first year (E), and this is extended, in both directions, the following spring (F). By the end of the second year the dune slopes should have assumed their permanent profiles (G). The arrow points from the shore. The width planted in G from the foot of the windward slope to the foot of the lee talus is 28 metres. (From F. Solger in *Dünenbuch.*)

obtaining between a bust modelled out of plaster and one carved by the chisel from a block of marble. It is sufficiently important to receive recognition by a special terminology.

The Littoral Dune: Details of Methods.—The initial mound, the nucleus of the littoral dune, is created by placing two permeable fences, 6 feet apart, parallel to the shore and at a distance from it corresponding to the position at which the crest of the littoral dune is required. The dune crest will ultimately form over the hinder of the two fences. The sand-catching fences consist of untrimmed pine branches, or other brushwood, standing about 2 feet 4 inches in height and bedded in the ground about 12 inches. The density of the fence should be such that the ratio $\frac{\text{brushwood}}{\text{interstices}} = \frac{1}{1}$. It is important that the top of the fences be level. The same method is employed to close any wind-cut gully or passage that may be present on a dune, except that more than two fences should be used with greater intervals between. Wattle hurdles or rude plank fences will produce the same result, but it is not necessary to use expensive appliances where simpler means are available, especially as the hurdles become buried and are non-recoverable. In Gascony this drawback is partially met by making the front fence of 6-inch planks stood vertically to form a palisading with 1-inch intervals between. When nearly buried these planks are raised to the necessary height and continue to serve. The back fence, which catches the sand that blows through, and gives a better profile to the dune, consists of hurdling; when buried it must be replaced.

If the fences are planted in early spring they should be buried by the summer, when new brushwood must be installed. It is quite remarkable how quickly a brushwood fence becomes buried under favourable conditions. We have seen a mound 3 feet high collect in less than a week. By autumn the upper tier of fences should be buried (fig. 15, profile D) and the first planting of Psamma can be put through.

To understand the method of planting adopted it is well to remember that the object in view is the equal collection of sand everywhere as it drifts and the holding of it in place.

This object could be achieved for a while by the use of dead cover suitably spread and fixed in the ground, but the brushwood so used would cease to function directly it was sanded over. By the employment of Psamma a living adjustable mechanism is obtained which continually grows up with the surface as it rises; its action being continuous and automatic.

As situations differ in respect of wind velocity, amount of sand drifted, and slope, it has been found necessary to vary the density of planting. Originally Psamma was planted in bunches, but this method has been replaced on the Baltic littoral by line planting. According to this practice the lines are ranged in two series intersecting at right angles, so that the ground is covered by a network of squares, the sides of which consist of Psamma, and in the meshes of which tufts or short lines of Psamma are also planted. The one set of lines (longitudinal) runs parallel to the shore, or, in plantings other than those on littoral dunes, at right angles to the direction of the prevalent winds. The object of the additional (transverse) system of lines is to prevent shifting of sand by winds other than those from the prevalent direction. Frequently, however, these transverse lines are dispensed with. Formerly, the size of the mesh was varied according to the circumstances of ground and exposure, but, this variation proving inconvenient in practice, a uniform mesh of 2 metres (6 feet 6 inches) has been adopted—adjustment to the special requirements being attained by varying the density of the sides of the squares and the number of tufts or short lines planted in the squares themselves. In Prussia four standard densities of mesh are employed: these are illustrated in fig. 16, and require no further explanation.

Each short line, whether in the side or in the interior of the square, consists of a row of from five to ten Psamma cuttings. These are pulled up from a convenient spot near by, especially from superfluous hummocks that require levelling. A notch is made in the ground with a small flat spade, the cuttings are placed in position, the notch closed and the sand stamped down. The cuttings should be used as soon after collection as possible, and if not required at once should be

covered with moist sand. The planting should preferably be done when the Psamma is not in active growth, i.e. in late autumn or early spring. Formerly the Psamma plants were raised from seed, but this has been largely abandoned in favour of planting, on account of the uncertainty of sowing.

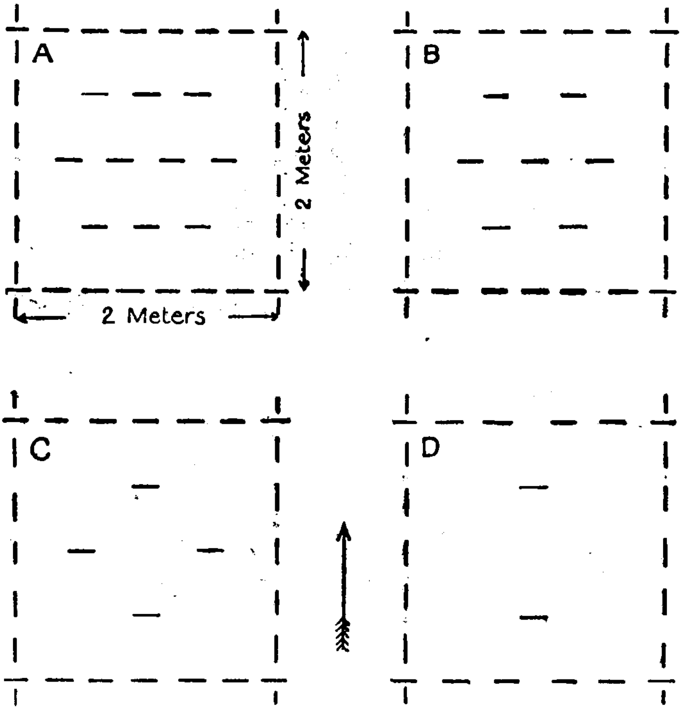


Fig. 16.—Diagrams of Standard 2-metre Squares as used on the Baltic for Planting Psamma Cuttings on a Littoral Dune

The density of the plantation is regulated by varying the number of short lines of cuttings in the sides and in the interior of the squares. A is the densest and D the most lax; B and C intermediate. The arrow shows the direction in which the prevalent wind blows. (After Gerhardt.)

To return to the planting of the embryo littoral dune in the late autumn of the first year. A Psamma net is planted from the seaward fence for a distance of 12 metres in the direction of the shore, the upper two rows of 2-metre squares according to density A; the lower four rows according to B (fig. 15, E). In the opposite direction (i.e. from the seaward fence landwards)

the transverse Psamma lines are produced a distance of 6 metres. The lines parallel to the fences are omitted, so that no obstacle may be placed in the way of the sand which reaches the crest falling beyond it as a lee talus. The actual crest ultimately forms above the rearward fence — some 2 metres behind the point at which the Psamma network stops. Longitudinal lines of Psamma are undesirable on the crest, as they tend to hold the sand with liability to the formation of projecting ridges or spurs overhanging the lee talus. Such spurs catch the wind and lead to trouble.

By the second spring, when the surface of the dune will have risen well above the buried fences, Psamma planting may be continued: four more rows at the foot of the dune—two of density type C and two of density D. The transverse lines are also continued an additional 2 metres beyond the lee talus (fig. 15, profile F). By the end of the year the littoral dune has assumed its final form of profile, the slope up to the crest being an even slope all the way (fig. 15, profile G). Had the Psamma been planted in equal density everywhere the outer dune slope would have developed a convex profile with a steep foot towards the sea, inviting undercutting by the waves.

It is almost unnecessary to add that the upkeep of the littoral dune is of the first importance. All injuries to the surface or edge should be repaired at once by the planting of Psamma alone, or, in serious cases, with the assistance of brushwood or wicker hurdles.

Crater-like depressions, or "blow-outs", are very likely to appear on littoral or other dunes, following injury by rabbits, the digging of holes, or wind excavation. Neglected, these blow-outs undergo extension and also tend to migrate, and may prove obstinate to treatment. Here, as in other cases, it is a question of sheltering the surface by adequate cover and planting Psamma.

The Wandering Dune. — The first step towards fixing wandering dunes is the prevention of movement of the bare sand by the use of cover. As compared with the construction of a littoral dune the problem is relatively simple, as it is not required as well to collect wind-driven sand. In principle all

methods agree in the employment of materials most readily available, and these in the minimal quantities that will give the required result.

Generally the cover relied on is dead, i.e. low palisades of trimmed sticks, about 1 foot high, with 6 inches buried in the ground. These palisades are run in parallel lines 12 feet apart, with similar lines intersecting them at right angles. In this way the ground to be stabilized is covered with a network of squares, the side of each square being 12 feet. One set of lines is orientated parallel to the direction of the prevalent wind, so that the winds may not be liable to blow continually along the diagonals of the squares.

On steep slopes, such as a dune talus, the sides of the squares may be contracted to 6 feet, or 9 feet squares may be used with additional palisades along the two diagonals. The second of these alternatives requires, however, about 16 per cent more sticks, and, of course, labour in proportion. The ratio adopted is $\frac{\text{brushwood}}{\text{interstices}} = \frac{1}{2}$, or even $\frac{1}{4}$ in sheltered places on the lee side of dunes. Pine sticks with the smaller twigs and needles removed are suitable for these palisades, or such other brushwood as may be available. Being of common occurrence on marshy ground, and in old creeks of reclaimed marshes near the sea, the dry stalks of the common reed (*Phragmites communis*) of the previous season are often employed to make the palisading, and they have the advantage of being easily raised to a higher level in case the sand drifts. They must, however, be packed closer than the $\frac{1}{2}$ ratio, as many straws get lost or broken.

Where seeds are sown direct on the unstable ground, as in Gascony, prostrate cover of pine branches is employed for protection. These are arranged overlapping like the slates on a roof, with the butts to windward.

Seaweed and sea grass (Zostera) from the drift line are sometimes employed as prostrate cover, as also the small twigs stripped from pine branches in preparing the latter for the palisades. There is, however, no restriction in the possibili-

ties. Thus near Port Elizabeth, South Africa, troublesome dunes, exceeding 5000 acres in area, have been rendered dormant by strewing them with city refuse, and then planting with two species of Acacia (*A. cyclopis* and *A. saligna*), mingled with an indigenous grass (*Ehrharta gigantea*).

Formerly wandering dunes were first netted over with Psamma squares as a preliminary to afforestation, but this practice has largely given place to the use of dead cover. Only when Psamma is available in superabundance, or the management favours adhesion to the traditional routine, does the method persist.

The next act is the improvement of the soil and the planting of seedling trees. For manure, what is most available is taken —loam, peat, organic soil from the salt marsh, mud dredgings from the harbour, &c. These have to be stored long enough to mature lest the seedlings be injured. The seedling trees, raised in special nurseries, are planted out in their second year, one per square metre. Thus a square with 4-metre sides would receive sixteen young trees.

In the selection of the species of trees, the primary consideration is to raise a covering that shall permanently hold the wandering sand. In North Germany, where the dread of the great white mountains of the eighteenth century still holds sway, the dune forests are regarded as protective belts, and their products are not exploited in any way except for materials to fix other dunes. The following are the trees which have been most extensively utilized, a selection based solely on their fitness for the special conditions. That is to say, these trees thrive best on the ground, and successfully resist the wind. They are not sensitive to sudden changes of temperature, they form a permanent canopy, and by the fall of their leaves continually improve the soil. Authorities place first the Mountain Pine (*Pinus montana* v. *uncinata*), from its high powers of resisting the most extreme conditions of wind, sea exposure, and dryness of soil. Moreover, its crown spreads laterally at an early stage and shelters the ground.

Pinus sylvestris grows well, but is really suitable for the less exposed positions only. The Spruce (*Picea excelsa*) and

Picea alba are well spoken of for special purposes. The Alder (*Alnus glutinosa*) is invaluable, and compares with the Mountain Pine in resistance to extremes. It has been much employed to form belts immediately behind the littoral dunes, and in general on the lower, moister flats. It thrives in pure formations. The Birch (*Betula verrucosa*) is valuable for mixing with other trees, especially with Alders, to fill gaps and to occupy the drier marginal belts. It has a high power of natural rejuvenation from seed.

In France, particularly on the long strip of coast from the Gironde to the Adour, marvellous results have followed the stabilizing of the dunes. The establishment of great forests here was started 130 years ago, largely at the instigation of Brémontier. The importance of both the littoral dune and the protective forest belt was appreciated at an early stage, whilst by planting largely the Pinaster or Maritime Pine (*Pinus Pinaster*), here well suited by the climatic conditions, a most valuable industry in the exploitation of this tree for turpentine and other products of the resin has been developed. Nor is this all, for the trees when they have yielded their resin furnish timber. The export of pit props to England alone is stated to reach 600,000 tons per annum.

Considerable areas of wandering dunes have also been planted with Pines at Le Touquet, S. of Boulogne, but much remains to be done.

In 1914 a project was investigated by the county anthorities for the construction of a high road to run from Rhyl eastwards, along the coast-line, and in rear of the sand dunes. Fig. 17 shows the scheme of tree plantation evolved for that portion of the road abutting on the edge of the landward sand slopes of the dunes.

In Gascony the method of planting differs from that on the Baltic. The Pinaster seeds are mingled with those of Gorse, Genista, and Marram Grass, and as sown they are covered with faggots. The Marram and low bushes make excellent cover for nursing the Pines. Where the conditions permit it is obvious that sowing will be much less costly than planting.

The United States of America, under their Department of

Agriculture, are fully alive to the importance of dune fixation, and grass planting on several areas has been put in hand. No doubt when the extent and potentialities of the coast-line of the vast continent of North America are realized, its maritime lands of every sort will be reclaimed and put to profitable uses.

New Zealand, with some 300,000 acres of drifting dunes,

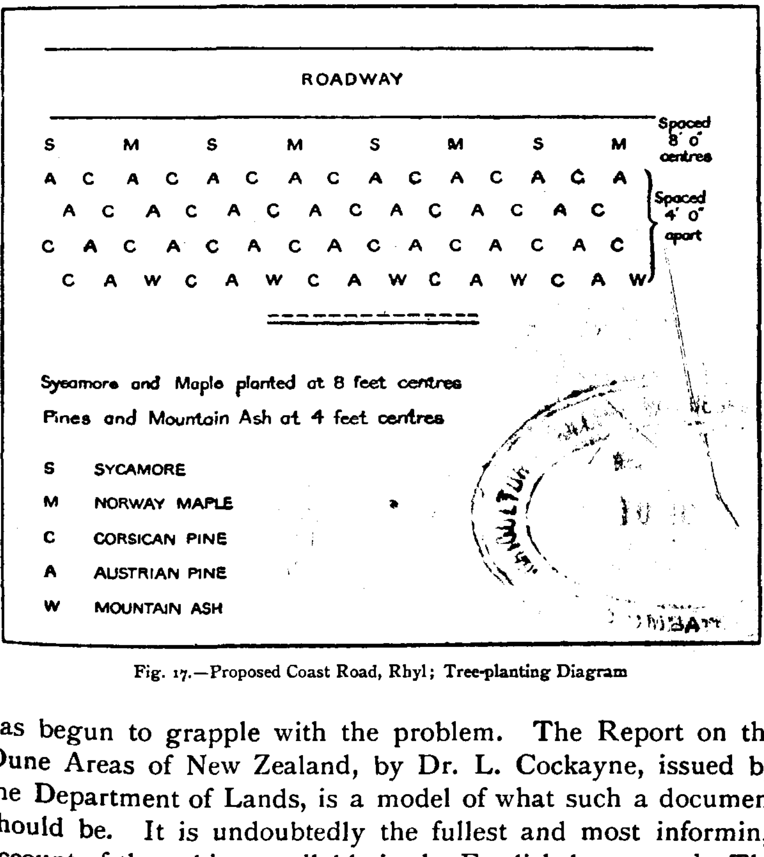


Fig. 17.—Proposed Coast Road, Rhyl; Tree-planting Diagram

has begun to grapple with the problem. The Report on the Dune Areas of New Zealand, by Dr. L. Cockayne, issued by the Department of Lands, is a model of what such a document should be. It is undoubtedly the fullest and most informing account of the subject available in the English language.[1] The report has especial value, as it is written in the light of experience gained locally.

Psamma is the staple plant for fixation purposes. For

[1] L. Cockayne, *Report on the Sand-dunes of New Zealand*, N.Z. Dept. of Lands, 1909.

holding wandering dunes no longer receiving fresh supplies of sand the Tree Lupin (*Lupinus arborea*) is recommended. This plant has no capacity for ascending to the surface in drifting sand, but it readily establishes and covers the ground till such time as the dune can be permanently afforested. Being a member of the family Leguminosæ, this plant, through its nitrogen-fixing root tubercles, exerts a favourable influence on the soil. For afforestation purposes Dr. Cockayne speaks in the highest terms of *Pinus insignis*, which we have reason to believe would prove successful in Britain. The tree is famous for its rapid rate of growth. He also draws attention to *Cupressus macrocarpa*.

Successful plantings of Psamma have also been established in Australia at Port Fairy (Victoria) and elsewhere.[1] The photographs of Plate VII show the first planting in progress, and the results after three years' growth. In the lower picture, cuttings of Psamma are being dug to continue the planting elsewhere. Plate VIII, 2, shows a recent dune planting on the Southport dunes (Lancashire) taken in 1911.

Holland is a country the existence of which depends on the maintenance of its sand dunes. These vary from 1 to 3 miles in width, and rise to a height of 130 feet. Essentially Holland has been fashioned by the skill and industry of its inhabitants out of the alluvial matter brought down by the Rhine and Maas, and accumulated behind a seaward belt of sand dunes, somewhat on the pattern of the Kurische Nehrung on the Baltic. The initial stages of Holland were laid down, according to the prevailing theory, at a time when the Straits of Dover had not yet opened, and the North Sea was, like the Baltic, a tideless gulf into which the Maas, Rhine, Ems, Weser, and Elbe discharged. When the English Channel became continuous with this gulf, and the tides gained access, the hitherto continuous chain of dunes was largely broken into the fragments now known as the Frisian Islands. A further expression of these more strenuous conditions was the inrush of the waters to form the Zuider Zee and the Dollart. The longest surviving strip

[1] See J. H. Maiden, "The Sand-drift Problem in New South Wales", in *The Forest Flora of N.S.W.*, pt. lvii, 1915.

Putting in the Young Psammas on a Bare Dune

Photos. J. H. Maiden

Digging up Psamma Cuttings after three years' growth

DUNE PLANTING AT PORT FAIRY, VICTORIA

of dunes is that extending north from the Hook of Holland to a point well on towards the Helder. This is Holland's primary bulwark against the sea, and no pains are spared to maintain it. Owing to the fact that these dunes are by no means continuously fronted with a foreland suitable for the construction of a littoral dune—in other words, that the sea has reached and is attacking the steep foot of the range—special measures have to be taken for the collection and holding of sand by the employment of fascines, brushwood, and Psamma. However, the Dutch engineers keep cool heads. They know that sand gnawed by the sea is still potential beach material, and will return to the shore; whilst sand blown from a dune and spread on the land is lost. These men are unequalled the world over at waging this species of defensive warfare.

Turning now to our own country, whilst it is certainly true that Psamma planting has been carried out sporadically for very many years, this has neither been systematic nor has it enjoyed the advantage of central control. Among examples of dune control, the Southport area in Lancashire and Lord Leicester's estate at Holkham in Norfolk may be cited. At the former, it is more especially Psamma planting that has been carried out (Plate VIII, 2), whilst Holkham has become quite a show place on account of the very successful planting of Pines, which has been carried out during the last fifty years along a sea frontage of some four miles, in addition to the regulation and protection of the marginal dunes. Perhaps 300 acres of dunes have been planted with Corsican Pine (*P. Laricio*), Austrian Pine (*P. Laricio* var. *austriaca*), and Scotch Pine (*P. sylvestris*). The Austrian Pine is used on the more exposed seaward margin, with the best results, the others in more sheltered positions. The aggregate result of this interesting experiment is a fine and impressive belt of woodland, vigorous and thriving, that should serve as an object lesson. It is not claimed that it constitutes more than a belt of protection, as the scheme of planting was not intended to be close enough for economic exploitation.

In our view much more attention might be paid to the

planting of dunes in this country than has yet been given to the matter. So far as we are aware no general report on the extent and circumstances of British sand dunes as a whole has ever been drawn up, so that it is difficult to estimate their aggregate area or dogmatize on their treatment. Whilst this country, unlike Gascony and the Baltic, is in no danger from extensive wandering of its dunes, the time has probably come when we can no longer afford to enjoy the luxury of so many waste areas of "joy lands" by the sea. The least that can be done is the tabulation of our resources of this kind, with a view to considering the matter of their control and profitable exploitation. Now that the utilization of Psamma as a substitute for Esparto grass has been favourably reported upon by paper manufacturers, we think the time has come when the conversion of some of our dune areas to this purpose should be proceeded with. And more particularly because, if successful, this industry would be based on raw material grown at home in place of an imported article brought from the Mediterranean. So far as we can see the primary protective function of Psamma would not be impaired by cutting it as a crop, provided narrow belts were left intact at proper intervals. The treatment of sand dunes, however, is only one department of the complex of problems which await attention in the organization of our coastal lands.

Photo. E. P. Farrow

Embryo Psamma Dune in the Flowering Stage (Blakeney Point)

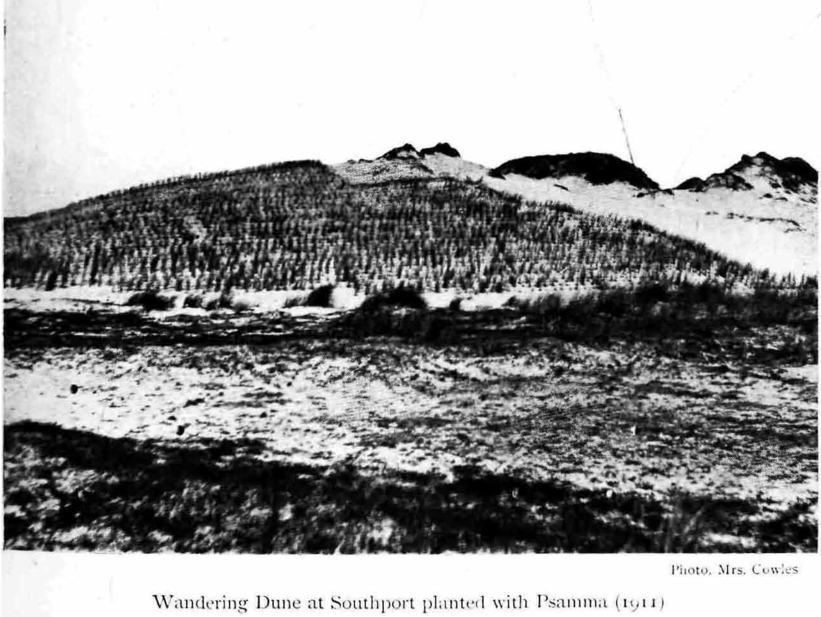


Photo. Mrs. Cowles

Wandering Dune at Southport planted with Psamma (1911)

the tidal currents, they may be drifted in certain definite directions. The driving ashore of these materials to form beaches is effected in the main by wind-wave action, as already described. The principal types of beach may be distinguished as follows:—

1. *The Fringing Beach.*—This is the simplest case, the shingle being directed and moulded by the shore currents and forming a strip in contact with the land behind. Illustrated on the English Channel, as on the coast of Sussex, and in France, S.W. of Dieppe.

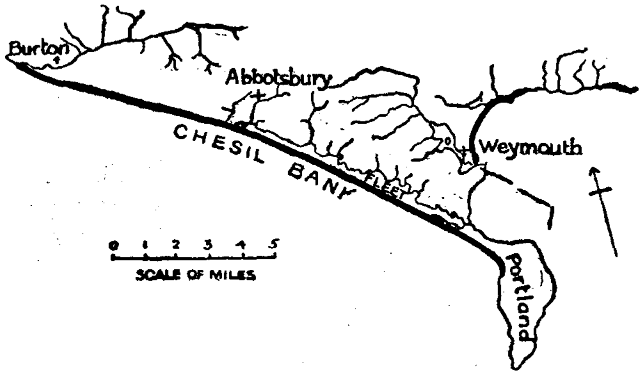


Fig. 18.—Sketch Map of the Chesil Bank (after Bristow and Whitaker), to show the relations of Bank, Mainland, and Fleet. Shingle is rendered in heavy black

2. *The Shingle Spit.*—This is produced when a coast-line suddenly changes its direction, turning landward, whilst the current pursues its original course so that it separates from the shore. The transported shingle accumulates along the line of the current to form a bank or causeway, often reaching a length of several miles. This type is attached to the shore at the point where the current leaves it, and then runs straight on with a gentle curvature to its growing extremity. The apex of this type is particularly liable to deflection as a landward hook.

Examples: Hurst Castle, Blakeney Point (with hooks), Northam Pebble Ridge (Devon), Aldeburgh, Calshot Point, Heacham Bank, Cemlyn (Anglesea).

3. The term *Bar* is given to a beach which runs parallel to the shore line but at some little distance therefrom, and is tied

to the land at both ends. Frequently a backwater is enclosed by it on the landward side (fig. 18).

Examples: The Chesil Bank, Slapton Beach, Pevensey Beach.

Whilst in some cases it may be that a bar is, historically speaking, a spit, the growing apex of which has become attached to a projecting point of land, it seems probable in others that the bar represents the surviving fragments of a former land extension out to sea that have been swept up by the waves, and in this consolidated form are slowly advancing landwards.

In respect of vegetation covering, however, the spit and bar present almost identical features.

4. *The Apposition Beach.*—In this type the materials instead of continuing their course along an existing spit or other beach accumulate in front of it. With the advent of a gale oblique to the line of foreshore such accumulations may be raised above tidal limits to form a bank parallel to the one previously in contact with the sea. Off-shore gales often produce successive closely approximated parallel beaches. From the above causes apposition beaches come into existence (as in the accompanying fig. 19), and, if the process be continued, very extensive ribbed areas of shingle are produced.

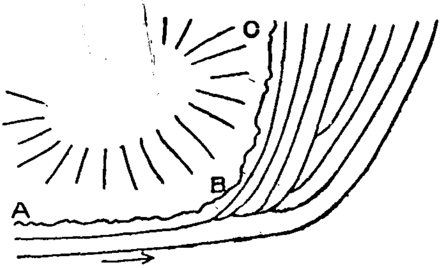


Fig. 19.—Apposition Type of Shingle Beach

ABC is a point of land; the arrow marks the direction of coastal drift; the successive beaches lie to the right of the figure. Modified from F. Drew.

The outstanding example of this type of accretion is Dungeness, where the area of accumulated shingle can hardly fall short of 10,000 acres. Other cases are Orfordness on the Aldeburgh bank, and Langney Point between Pevensey and Eastbourne. In both the latter the apposition beaches form as it were an excrescence, the first on a spit, the second on a bar. Complications of this kind are by no means rare.

The great feature distinguishing apposition beaches from the preceding types is that they are not mobile. Spits or bars in

consequence of the battering of the waves move landwards; apposition beaches, except, of course, the outmost and last-formed rib, are inaccessible to the waves, and their shingle is perfectly stable. The problem of their reclamation is quite different from the other categories of shingle.

The special conditions of Spits and Bars may now be set forth briefly.

Spits and Bars.—*Topography.*—Commonly these banks, which follow a course more or less parallel to the shore, act

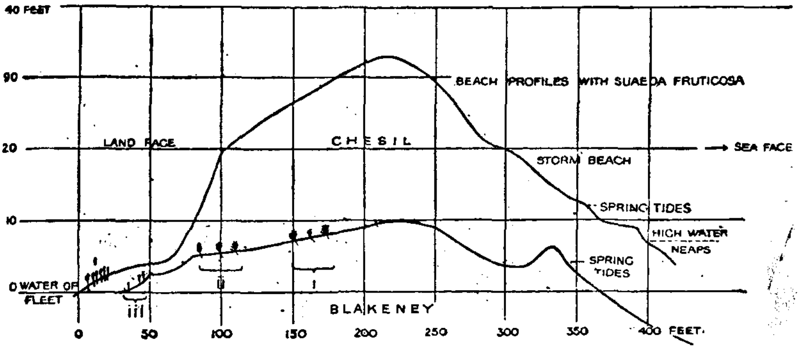


Fig. 20.—Profiles of the Chesil and Blakeney Beaches plotted to the same scale

The datum levels to which they are referred are in the case of the Chesil the water-level of the Fleet, and in that of the Blakeney Bank the surface of the salt marshes. The figure also shows the positions of the *Suæda fruticosa* belts in both cases—marked I, and I, II, III, respectively.

as the bulwark protecting a backwater, tidal flats, or reclaimed marshes from the sea. Spits, as a rule, are backed by salt marshes, whilst bars protect backwaters (Slapton Beach), chains of lagoons (Audierne shingle beach, Finistère), or marsh and meadow land (Pevensey Beach). In the case of the Chesil Bank the backwater or Fleet connects with the sea between Portland Island and the mainland, and is thus subject to slight tidal influence. Such beaches rest on the edge of a coastal shelf and are slowly driven landwards.

In profile or section these beaches are comparable, showing many features in common. Two such profiles of the Blakeney and Chesil Banks, respectively, are illustrated in the accompanying fig. 20.

An average section of the Blakeney Bank is some 350 feet

wide from high-water mark on the sea face to the lee edge on the marshes. The sea face ascends at an angle of some 15 degrees to the crest, which is 10 feet above the marshes and perhaps 6 feet above high-water mark. The lee slope is a gentle one of 5 to 8 degrees, the last few feet descending abruptly *to the marsh at the angle of repose of the shingle* (about 35 degrees). The waves of heavy foreshore gales when they coincide with very high tides top the crest and drive shingle down the lee slope. In this way the lee edge advances slowly and intermittently across the marshes, perhaps 30 feet in the last twenty years, or an average of 1 foot 6 inches per annum, but varying from place to place.

The Chesil Bank is much higher, standing 34 feet above the water-level of the Fleet (as determined at a point half-way between the letters L and B in "Chesil Bank" (fig. 18, p. 88). The width of the bank is about 400 feet from water to water at ordinary high tide. The sea face is steep, but the most characteristic feature is the steep slope on the lee side descending to the terrace (about 70 feet wide) at the edge of the Fleet. Notwithstanding its immense height waves break over the crest in heavy weather carrying shingle with them. This power of the waves is well illustrated by the following incident of the war, for the particulars of which we are indebted to the courtesy of the Earl of Ilchester, Lord of the Manor.

Throughout the summer of 1915 and the following winter one of the boats of H.M.S. *Formidable* lay derelict half-way down the lee slope of the Chesil opposite the decoy at the Abbotsbury Swannery. This battleship was torpedoed in mid-Channel on the morning of New Year's Day, 1915, and the boat drifted ashore at high water early in January. "It was found and pulled by about thirty men some way towards the crest of the beach, but it proved too heavy for them to get it anything like to the top. About a month afterwards a very heavy sea was running, and it threw the boat from the sea side of the crest to its present position. It has not been handled in any way since, nor have I heard of any intention of removing it."[1] As

[1] Quotation from letter dated Feb. 18, 1916, from Mr. J. Hutchings, Lord Ilchester's agent at Abbotsbury.

previous episodes of the same kind are on record,[1] it is evident that the wave that lifted the *Formidable's* boat over the crest was a representative feat of sea action comparable with the wave transport of rock masses on Bound Skerry. In one case a heap of angular blocks up to 9½ tons in weight was huddled together at an elevation of 62½ feet above mean sea-level; a block of 5½ tons was quarried and shifted by the sea at a height of 72 feet above mean sea-level.[2]

Wave action on the face and the hurling of shingle are phenomena normal to the Chesil Bank. Its gigantic height is doubtless correlated with this liability, which in its turn depends on the great "fetch" out into the Atlantic. The almost unlimited resources of the Bank in materials have enabled the waves to do full justice to their lifting power. In contrast we may cite the Northam Pebble Ridge at Westward Ho, where the forces at play are also enormous but the materials scanty. The result is a beach of no great height, and with such capacity of travel that a single storm has been known to drive it landward a distance of 30 feet.[3] The beach at Blakeney, on the other hand, though reaching only 6 feet above spring tide high-water mark, is amply supplied with materials. The relatively low altitude of the crest depends on the height of the waves, which is vastly inferior to the Atlantic billows of the Chesil.

Nature of the Mobility.—In order that it may be possible to grapple with the question of the establishment of vegetation on shingle liable to mobility, it is necessary to consider closely the incidence of this factor. Before doing so, however, it will be well to discriminate between beaches thus affected and such as are immobilized. To the latter class of course belong apposition beaches (cf. p. 89), and these need no further consideration here. The hooks, however, which develop on shingle spits deserve attention. Commonly, as a spit approaches its full extension the apex is liable to be deflected in the landward direction to form a hook. Often (e.g. Hurst Castle, see fig. 21) a succession of such hooks is produced by the continued growth

[1] J. Coode, *Min. of Proc. Inst. C. E.*, Vol. XII, p. 545.
[2] Stevenson's *Construction of Harbours*, p. 45.
[3] W. H. Wheeler, *The Sea Coast*, 1903, p. 329.

of the beach in its original direction—the new growing point being grafted, as it were, on to the base of the last-formed hook. When several hooks have been formed all but the last one are washed by relatively tranquil waters, and are not subject to buffeting by waves of any magnitude. Their shingle is thus no longer kept on the move and becomes dormant. One striking consequence is a marked change in the vegetation. Plants not found on mobile shingle make their appearance, whilst several of the original colonists disappear, the settlement of which dated back to the period when the hook was in contact

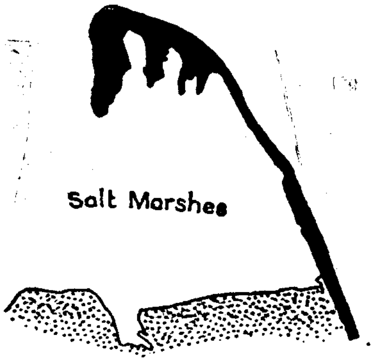


Fig. 21.—Shingle Spit with Hooks, illustrated by the Hurst Castle Bank

with the open sea. A most striking example of this apparition of new plants on hooks is to be seen on the Hurst Castle Bank, where Golden Samphire (*Inula crithmoides*) forms dense continuous zones on the shore lines of the hooks—than which, when flowering in August, no more vivid spectacle in the botanical world can be imagined. Another plant, peculiar to dormant shingle, is the East Anglian *Statice binervosa.*

Occasionally hooklike embankments of shingle are produced, not in the regular apical growth of the system, but as local overthrows at some point of weakness or insufficient height in the line of the main beach. Such an one occurs on the beach at Shoreham, a furlong to the east of the present outfall of the River Adur. When mingled with true hooks such overthrows or pseudo-hooks are difficult to distinguish from low and wasted

hooks, especially in the absence of reliable historic data. Distinct as they are from a developmental point of view it is convenient to treat them as true hooks—with which, indeed, they have otherwise much in common.

Coming now to the subject of *mobility*, which affects in varying degree all shingle beaches to which the sea has access, so long as the sea beats on a shingle bank so long will its component parts be liable to displacement, unless it be covered and protected by dunes, or—as very rarely happens in Nature—becomes so densely clothed and bound with a robust vegetation as to defy the violence of the elements. There are three principal ways, quite distinct from one another, in which shingle is kept mobile; though all are operative on nearly every bank, their relative importance will vary in different cases.

A. **Wave Impact.**—When a great wave plunges on the face of a shingle beach it rushes up the slope, carrying with it much of the surface shingle which it encounters. As it approaches the crest it will on account of its diminishing velocity drop some of its burden of shingle. If the crest be overtopped a portion of this will be carried over to the lee side, whilst the water as it runs off on this side under the influence of gravity will carry with it the surface layer of the shingle over which it runs. Whether the water reaches the foot of the slope or whether it drains off through the beach will depend on the amount of water in motion and on the porosity and inclination of the shingle. The chief points to be emphasized are:—

(1) That the displacement of shingle by the waves is superficial;

(2) That if much water is traversing the crest a large part of the displaced shingle will be carried to the lee foot of the bank, where it will be thrown as a talus or fan encroaching on the marshes beyond.

In this way the crest will be lowered—an effect that is cumulative, for the more the crest drops the greater is its accessibility to the waves. One may see a single gale lowering the crest of a beach two or three feet, at the same time transporting great volumes of shingle down the lee slope. The result is a definite

permanent advance of the beach in the landward direction—for there are no forces available to restore the *status quo.*

These points are well illustrated by the effects of a gale in November, 1913, on the Shoreham Beach, a mile or so west of the harbour entrance. This part of the beach consists of bare shingle; its front is protected by groynes at 100-yard intervals, but there is no sea-wall or breastwork parallel to the shore. It carries a settlement of timber bungalows behind the crest, and in rear of these a line of telephone posts. The accompanying diagram (fig. 22) is a profile showing the general relations of the beach and the structures upon it before (dotted)

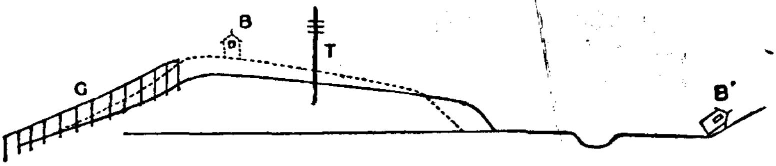


Fig. 22.—Diagram of Profile through Shoreham Beach, showing movement of shingle on the occasion of the gale of November, 1913

The dotted line shows position of shingle before, the continuous line after, the gale. The bungalow (B) has been washed down the lee slope and drifted across the marshes to a resting-place on the bank beyond (B′). T, Telephone post which stood firm. G, Groyne left standing on the face.

and after the gale (continuous lines). The groynes had not the slightest effect in retaining shingle as the gale was on-shore.

The shingle was washed away, layer by layer, and carried as an extension of the lee talus. The bungalow was carried with it, and, drifting over the marshes, was left by the tide at B′. The telephone posts stood firm, because they were planted deeply in the shingle below the zone of mobility. Indeed, the whole row of posts remained in perfect alignment with wires as taut as before the gale, showing that shingle displacement is a surface phenomenon. Had the owners of this and the other displaced bungalows had the inspiration to mount them on piles buried deep in the beach, they would have been spared not a little inconvenience. Parallel results have been noted on the Pevensey and Blakeney Beaches under like conditions. From the point of view of protection, it is thus evident that the

important thing is to prevent the surface layer of shingle from acquiring mobility.

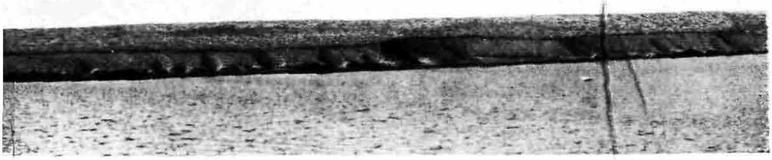
B. Percolation.—This depends on the open texture of the material and the difference in level of the water on the face and back of the shingle beach. Most shingle beaches are liable to percolation at high water, or when breakers hurl themselves on the front. The Chesil Bank offers an extreme example. Owing to the slight effect of the tides on the water-level of the Fleet (which oscillates about mean sea-level), the difference in level within and without may reach a height of 6, 8, or even 10 feet. Moreover, as this bank consists of remarkably pure shingle with but slight admixture of finer materials, the conditions for percolation are unusually favourable. The result of this action is the production of numerous ravines or "cans" on the lee side, from the bottoms of which shingle is displaced and shot out in the form of talus fans into the Fleet (fig. 7A, p. 42). It is the aggregate of these fans that constitutes the terrace. This displacement of shingle naturally communicates itself to the back and sides of the ravines, which are kept perpetually on the move and bare of vegetation.[1] Plate IX, 1, shows a number of ravines seen over the Fleet; the black bushes on the terrace are *Suæda fruticosa*. A projecting fan is shown in Plate IX, 2.

Shingle spits with a nearer approximation to equality of water-level on the two faces are usually affected only to a trifling extent—as at Blakeney Point[2]—with production of gullies at the foot of the bank, of slight vertical extension. In some cases the materials have become so completely consolidated that percolation does not take place, as for instance Slapton Beach, where the backwater (Slapton Lea, famous for its freshwater fish), though distant but a stone's throw from the tide mark, is immune from contamination by salt water.

C. Scour.—Beaches sometimes suffer erosion on the landward side when in their advance they impinge on channels and tidal creeks. In this way a talus may be kept active for an indefinite period. Where estuaries are exposed and the land-

[1] Phenomena associated with percolation on the Chesil Bank are described in F. W. Oliver's "The Shingle Beach as a Plant Habitat", *New Phytologist* Vol. XI, p. 86.

[2] Under certain conditions well-marked ravines occur here. Cf. pp. 233, 234.



Chesil Bank seen from the Mainland over the Fleet. The steep bluff is scored with Percolation Ravines or "cans". The dark bushes are *Suæda fruticosa*

Chesil Bank; terrace and Suæda fringe. The point in foreground projecting into the Fleet is a fan talus ejected from a ravine

West End of Chesil Bank near Burton Bradstock; Sheep are feeding on the Sea Campion (*Silene maritima*), 1911

ward fetch considerable, wave action may have an analogous effect, with the result that the beach undergoes local attrition. Examples of this are included in our chapter on Blakeney Point (pp. 233, 237).

D. Uncovering.—A fourth source of erosion to which shingle beaches are liable is exposure or uncovering, owing to the sand dunes which encumbered them being blown away. Some beaches acquire a covering of sand-hills *pari passu* with their formation, and as the tip advances the source of sand on the foreshore moves forward in sympathy. Under these circumstances the dunes are starved of sand, so that losses are not made good. Should the dunes become inhabited by rabbits, and this is generally the case, they will in time be blown away unless they have been planted with pines or other ligneous vegetation. The areas of shingle thus exposed are very sterile and difficult to colonize with plants, and, if suitably placed, they are liable to erosion through wave impact.

The Plant Covering and its Stabilizing Effect.—Though it rarely, if ever, happens that plants which spontaneously colonize mobile shingle beaches so dispose themselves as effectively to render the beach absolutely dormant, nevertheless the matter deserves the most careful study, for it is patent that by following Nature's lead this result is to be reached.

The number of species of plants to be found growing wild on shingle beaches in various parts of Britain is considerable, 120–150 perhaps. The seeds of these arrive by various agencies —tidal drift, wind, by means of birds, and no doubt by unconscious human agency. In addition to the above, which arise and establish from seed directly on the beach, there is a further element derived from the terrains (marshes, pastures, &c.) which the beach overruns in its landward travel. Certain of the plants of these grow through the invading shingle, take root therein and lose connection with their original ground. Such plants may be termed Anarhizophytes.[1] Of all

[1] The term *anarhizophyte* is suggested for any plant having the capacity to root in terrain which invades and overlies its original habitat or place of establishment. This capacity is widely spread and plays an important part in Nature. *Suæda fruticosa* on shingle, Psamma on sand dunes, and Armeria and other perennial halophytes of the salt marsh are outstanding examples from the seashore.

these various sources by far the most important is the tidal drift. This reaches both sides of the bank, and is liable to include seed derived from both near at hand and far away. Though the great majority of shingle plants are, when growing, intolerant of sea water, in which respect they agree with the plants of the sand dune, the seed is so well protected by its coat that salt water does not penetrate, and thus is just as serviceable as fresh water as an agent of dispersal. Nor is it absolutely necessary for seeds to float to reach the drift line. In shallow estuaries, in addition to the floating or surface drift, there is also a bottom drift, which reaches the same destination.

In the following enumeration is named a very small selection of the plants which thrive naturally on shingle in Britain, and which promise to perform some useful function in relation to our object. With these are added notes drawn up to indicate the special rôles which they play on mobile shingle. It is, of course, understood that the plants will only establish naturally on the habitat from seed during intervals of quiescence.

Rumex trigranulatus (Sea Dock). This plant is one of the commonest and most characteristic of shingle plants, often occurring with a density of one per square foot. A perennial, establishing freely from seed, it develops a long fleshy tap-root, descending vertically into the shingle a foot or more deep. Its leaves remain near the ground, partly protected by the dead leaves of the previous season, except at the time of flowering, when the stem elongates. In obstructing or retarding the movement of shingle it has an appreciable value, particularly when it grows through continuous mats of *Silene maritima* or *Arenaria peploides*, towards which it acts as a *point d'appui*. Its bulky underground organs are further of value in manuring the shingle, thus providing food for other plants. Odd as it may appear in a plant growing within a few yards of high-water mark, the Sea Dock is not a halophyte; that is to say, the living tissues of its foliage, &c., are not organized to withstand wetting by sea water. In the event of a summer gale driving fine spray over the beach at the time of flowering, the shoots and inflorescences collapse, hanging brown and dead in a few days' time. However, the permanent system of the plant survives

Photo. E. J. Salisbury

Arenaria peploides, with *Rumex trigranulatus* behind
(Blakeney Point)

Photo. Dr. S. Hastings

Crithmum maritimum. Bouche d'Erquy

SHINGLE PLANTS

and new shoots are pushed out. This susceptibility is shared by not a few plants of those portions of the shingle beach that lie above ordinary tidal limits, and the same is true of the majority of dune plants. Nevertheless the mortality from this cause is almost negligible (see Plate X, 1).

Glaucium luteum (Horned Poppy) is another plant of essentially the same type as the Dock, i.e. with deep vertical tap-root. It establishes freely from seed in great numbers, and occurs on barer ground than the Dock. It is indifferent to sea water, owing to its covering of silvery hairs which render it unwettable.

Crambe maritima (Sea Kale) is a much more substantial plant than either of the foregoing. It develops deep-reaching rootstocks and roots, and as it generally occupies the ground densely when it occurs, it must have no little value as a strengthener of a beach. Sea Kale grows plentifully on the sea face, just above high-water mark, on certain sectors of Pevensey Beach, on Calshot Spit, and on Cemlyn Spit in Anglesea.

Contrasting with the above, which conform essentially to a *palisade type*, are the *mat plants*, which in varying degree form a woven fabric bedded in the surface layers of shingle.

Arenaria peploides is an extreme example of the type. The above-ground portions (Plate X, 1) form extensive sheets of close-crowded shoots prostrate on the ground or standing a few inches above. The leaves are glossy, bright-green, and succulent. In the shingle the slender rhizomes form a close plexus, reaching from the surface downwards for a foot or more, whilst the strands run in all directions. These mats often cover large areas, and as they tend to occur on and near the crest, have a great value in binding the shingle together. Where the sea overruns a crest clad with this plant, the amount of lowering from this cause is markedly less than on corresponding positions from which Arenaria is absent. The shingle-laden waves certainly abrade the surface layer of the rhizome-plexus, but in no case that has come under our observation have they extirpated it. Invariably the carpet is completely regenerated from the surviving portions the following spring. When

Arenaria occurs in small patches on the crest or on the seaward slope, these often stand out as hummocks 10 inches or 1 foot above the level of the adjacent bare shingle. The plant is evidently a useful adjunct in stabilization. It has, however, an apparent drawback in that it occurs naturally only on beaches with a moderate admixture of sand with the shingle (e.g. the Blakeney Bank). Whether it would establish if planted on pure shingle we are unable to say.

Two other plants of the same habit, fully worthy of mention, are *Convolvulus Soldanella* (the Sea Convolvulus) and *Lathyrus maritimus* (the Sea Pea). Both have a predilection for the upper parts of shingle beaches right up to the crest. The Pea covers immense tracts of the Chesil Bank, and has, in addition to its mechanical value (which is, however, inferior to that of *Arenaria peploides*), the further advantage of possessing, in common with other leguminous plants, nitrogen-fixing root nodules. In this way it enriches the ground which it occupies with combined nitrogenous food. *Lathyrus maritimus* is eagerly devoured by cattle that stray on the beach, whilst hares travel long distances to feed on it.

The rapidity with which these mat plants extend their area when once established is illustrated by the following data, referring to two plants of *Convolvulus Soldanella* growing on the crest of the Blakeney Bank. In the year 1909 each plant occupied an area of 9 square feet; the accompanying table gives the area of each in subsequent years. Plant B occupied slightly the more exposed position.

CONVOLVULUS SOLDANELLA

	Area in Square Feet in Successive Years.				
	1909.	1910.	1911.	1912.	1913.
Plant A	9		180	440	525
Plant B	9			180	350

Another mat-forming plant is *Silene maritima* (Sea Campion). It is the most universal of all shingle plants, and is

perfectly hardy and proof against salt water, On a beach the level of which is not rising by surface accretion Silene plants commonly establish, each with main descending tap-root and a dense fringe of grey-green leafy shoots resting freely on the surface like a mop. When shingled over, however, buds push from these branches and from the upper part of the tap-root to form rhizomes, which interlace freely, forming a mat like that of *Arenaria peploides*, and playing a comparable mechanical rôle in binding the shingle. Silene may not be an ideal plant

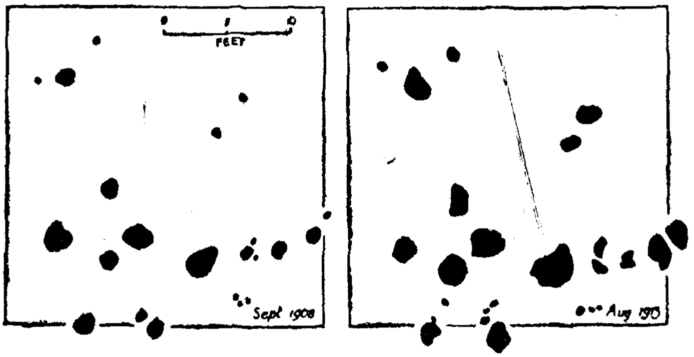


Fig. 23.—Charts of Identical Area of Mobile Shingle on Crest of Blakeney Main Beach, showing distribution and spread of plants of *Silene maritima* in Sept., 1908, and Aug., 1913, respectively. The plants have all remained, have expanded, and have undergone a slight migration away from the sea face, which is beyond the top of the charts. Scale 1/140.

for the purpose, but as it grows freely everywhere from the crest to the lee margin, it is best regarded as an ally and not as a weed. The great persistence of *Silene maritima* on mobile shingle is illustrated by the accompanying charts, showing distribution and spread of the plant on the same area of the crest of the Blakeney Beach at an interval of five years. Practically all the 1908 plants are present on the 1913 chart; they show marked expansion (fig. 23).

Crithmum maritimum (Samphire) should not be lost sight of. Characteristically it is a cliff plant, but when it occurs, as it occasionally does, on shingle beaches (e.g. Hurst Castle, Chesil), it tends to form extensive patches of robust plants, closely covering and holding the surface (cf. Plate X, 2). How

it would behave when shingled over we do not know, nor with what ease it establishes. Apart from these points, it is a vigorous and close grower, which merits further attention.

Of the grasses *Triticum junceum* is the most promising, as it forms rhizomes freely, and is tolerant of shingling over.

Elymus arenarius (Lyme Grass) takes tenacious hold of shingle with which a fair proportion of sand is mingled. Notwithstanding its great size it resists uprooting by storm waves, and holds shingle thrown over it. As it tends to form fairly large patches, it is valuable as a beach strengthener.

Suæda fruticosa (Shrubby Sea Blite). This is a woody shrub reaching a height of from 3 to 4 feet. Of native plants it is by far the most important beach strengthener, and may be placed in a class by itself. Being satisfied that the problem of shingle-beach stabilization is to be solved by the study and exploitation of the natural capacities of this plant, we make no apology for introducing it here at some length.

The plant is of bushy (fastigiate) habit, recalling a juniper or low yew tree in appearance. The centre of its distribution is the Mediterranean; it is found on the Brittany coast and abundantly on the Chesil Bank, and on shingle on the North Norfolk coast from Weybourne to Hunstanton, and on the east side of the Wash. More sparingly it occurs on sea-walls and shingle about the Essex marshes, in Poole harbour, and near Cardiff. Otherwise it is absent from Northern Europe. The numerous branches bear a dense foliage of linear, succulent leaves (fig. 24, B shows a twig, natural size), often tinged with crimson or purple. It is practically evergreen, the leaves being held through the winter till the next year's buds begin to expand. Inconspicuous greenish flowers occur in the leaf-axils (fig. 24, B). The flowering time is August, and the little fruits, each containing one glossy black seed, should be ripe by the end of November. Experience shows that bumper harvests occur on the average about once in four years. In some years, especially those with dull, wet autumns, hardly a seed matures, however promising the flowering may have been. The matter is of importance, as the simplest way of raising a crop is by seed.

In England *Suæda fruticosa* grows characteristically on maritime shingle, and preferably on such zones as are covered at the spring tides. The plant is consequently a halophyte. It is also able to maintain itself perfectly where salt marsh turf has overlaid the shingle to a depth of 1 or 2 feet. Occasionally it is found sporadically on salt marshes, apparently quite inde-

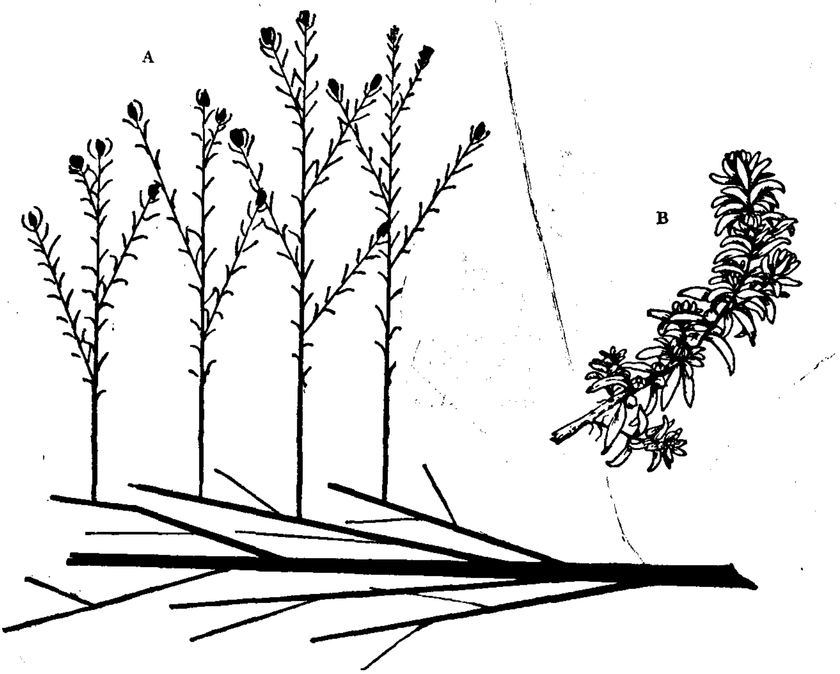


Fig. 24.—A, Diagram of prostrated branch of *Suæda fruticosa* rejuvenating in the shingle from lateral buds. B, Twig with leaves and flowers, nat. size.

pendent of any shingly substratum, and also on clay sea-walls. It prospers on sand dunes[1] when continuous supplies of fresh sand are brought by the wind; its range of habitat is thus considerable. In ordinary garden soil, and even in a London window-box, it flourishes amazingly. When better known, Suæda will doubtless be cultivated as an ornamental shrub.

Here we are concerned with *Suæda fruticosa* as a shingle

[1] Doubtless occurring as an anarhizophyte originally established on shingle.

plant. According as the shingle is dormant or mobile, Suæda shows a great difference in habit.

On dormant shingle (e.g. the hook of a spit) the bushes acquire one or more thick principal stems, which may reach 2 inches in diameter. These generally show a strenuous and contorted growth.

On mobile shingle, that is to say, in positions where the plant is liable to be shingled over from time to time, the habit is entirely different. The shoots at all stages of development arrest the flowing shingle, at the same time being tilted forward. When overwhelmed they are prostrated, and new, erect-growing branches rejuvenate by the elongation of lateral buds, so that for each branch laid low a sturdy thicket appears (fig. 24, A). By the second year these buried branches become rooted, and independent of the original plant to which they belonged. As the process is repeated from time to time the area covered by the original bushes undergoes great extension, the ground being occupied by crowded besom-like complexes which retard and hold the shingle. The value of the plant depends on this unlimited capacity of vegetative rejuvenation when capsized and on its power of holding the shingle. In this way the level of the beach is materially raised where the bushes occur.

The history of the establishment of Suæda on an active beach is as follows:—Seeds brought to the drift line at the lee foot germinate during a period of quiescence. The seedlings, which, in seasons when seed is abundant, are very numerous, develop extensive tap-roots in the mud and humus occupying the interstices between the pebbles. They sometimes grow as thickly as twenty to thirty to the square foot. By the first summer the seedlings may be 6 inches high on the average, and by the second 9 inches to 1 foot, already sturdy and branched. In the absence of shingling over the plants continue to expand into rounded, much-branched bushes 3 feet in height after five or six years. In the event of shingling the plants are prostrated down slope and send up numerous branches to the surface in the manner already described. The result is that the upper layers of shingle are occupied by a plexus of horizontal branches which become rooted and function as rhizomes, whilst

from the surface projects an ever-widening thicket of closely-packed, erect, woody shoots. As successive prostrations tend to be in the same direction, the plant as a whole grows obliquely upwards in staircase fashion.

Following successive advances of the beach a new lee edge forms each time and becomes populated by seedlings from the drift line. Thus it generally happens that the Suædas occur in successive zones above one another, the zones being more or less parallel to the edge of the beach. It is only a question

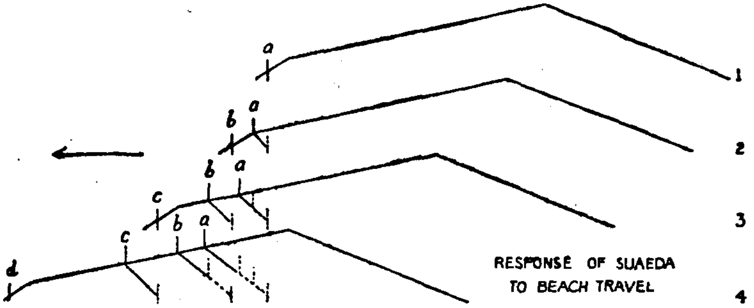


Fig. 25.—Diagram illustrating the Mode of Ascent of *Suæda fruticosa* from the Place of Establishment on the Lee Fringe up to the Crest of a Travelling Beach

Four profiles (1, 2, 3, 4) in the travel of the beach are shown, and four Suæda plants (*a*, *b*, *c*, *d*) successively establishing at each stage are represented. The existing portions of the Suædas are given in continuous lines, the parts which have disintegrated by broken lines. The direction of beach travel is from right to left.

of continued beach travel for the Suædas to reach the crest and eventually the sea face.

For clearness, the history of the passage of Suæda up the bank is summarized in two diagrams. At 1, fig. 25, a seedling plant *a* has established from tidal drift on the dormant lee fringe. In 2 the beach has advanced a short distance landward, the shoot of the plant *a* being deflected forwards by the shingle and pushing up buds into the air (one only represented). Meanwhile another plant *b* has established on the fringe. In 3 there has been further advance; the plants *a* and *b* behave as before, and a fresh plant *c* has arisen in the new fringe. Finally in 4 there has been a further considerable advance of the bank, with shingling over of *a*, *b*, and *c*, followed by the usual rejuvenescence. A seedling *d* has established on

the fringe. The diagram (fig. 25) shows how longitudinal zones would arise were the same process repeated throughout the length of the beach.

In fig. 26 the career of a single specimen is traced from the lee fringe of a beach in position I to its crest in position XI as the result of ten successive advances of the beach, which, as before, is travelling from right to left. The dotted lines represent the successive positions occupied by the plant. It will be appreciated that when a plant has reached the crest, the actual position from which it started (originally at the lee edge) would have to be sought on the sea face of the beach somewhat above the neap tide high-water mark. As a rule,

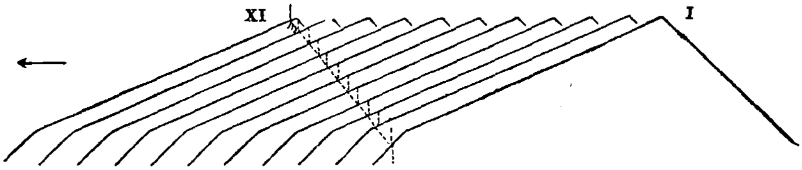


Fig. 26.—Collective Diagrams of Profiles of Beach travelling from right to left. The dotted line represents the course followed by a Suæda plant established at the foot in the first profile (I). In the last profile (XI) the plant has reached the crest.

of course, no trace is to be found, but in the case of narrow beaches travelling rapidly the old stools may sometimes be found persisting on the foreshore after the beach has passed right over them.

Two further points may be mentioned. The rejuvenescence of Suæda after shingling is accompanied by increased vigour of growth—far exceeding that of plants on stable ground. The same applies generally to all species of plants which tolerate shingling. Their green becomes more vivid and their flowering is profuse.

When a Suæda has ascended some distance up a beach it will be found on uprooting that the underground stem, or rhizome, dies out not more than 3 feet from the surface—except in the case of quickly-moving narrow beaches. This arises from the marked quality of rapid disintegration which distinguishes these rhizomes. This early mouldering into humus is probably of no little importance in the provision of food to

Suæda fruticosa and the plants which characteristically settle around it; it means that combined nitrogen does not long remain locked up in superfluous members of the plant, but gets early into circulation again.

The Effect of Suæda Bushes on Beach Travel. — By examining the relief of a beach carrying a natural vegetation of Suæda bushes, and comparing it in detail with the distribution of the bushes, it is evident that the closest relation obtains between the two. The spots at which bushes are firmly attached to the beach tend, by the collection of shingle, to project above the general level, whilst the existence of these salients diverts the natural flow of shingle along lines which pass between the bushes. These lines of shingle-transport, or dynamic lines, tend to take the form of shallow gullies reaching from the crest via the gaps between the bushes to the lee margin, where the talus fans of their discharge accumulate.

This condition is well illustrated on the Blakeney Bank, where the Suædas occur in three discontinuous longitudinal belts or zones. In fig. 27 we give a typical strip of this bank, 50 feet wide and stretching from crest to marsh. The Suæda bushes are plotted in black, and, by means of contour lines drawn for every half-foot from crest to marsh level, the principal features of the relief are exhibited.

The contour lines show that two gullies start from the crest at points opposite the gaps in the upper Suæda zone, and that after traversing this zone they continue in the same way through the middle zone, and then die out below on the fan terrace between contours 3.5 feet and 4 feet. Towards the edge of this almost level terrace three little furrows are shown, corresponding to the spaces between the depots of accumulation of shingle which these gullies have brought. The edge of the fan below the terrace consists of shingle standing at a steep angle.

We may note in passing the enduring permanence of these dynamic lines of shingle flow. It sometimes happens for a long series of years that no fresh shingle is thrown over at a certain part of the crest; all this while the gullies and the bushes maintain their original topographical relations, and whenever the moment arrives when shingle transport is re-

umed this will follow the original lines. Parts of the Blakeney ank illustrate this (see fig. 28). From 1907 to 1912 to our

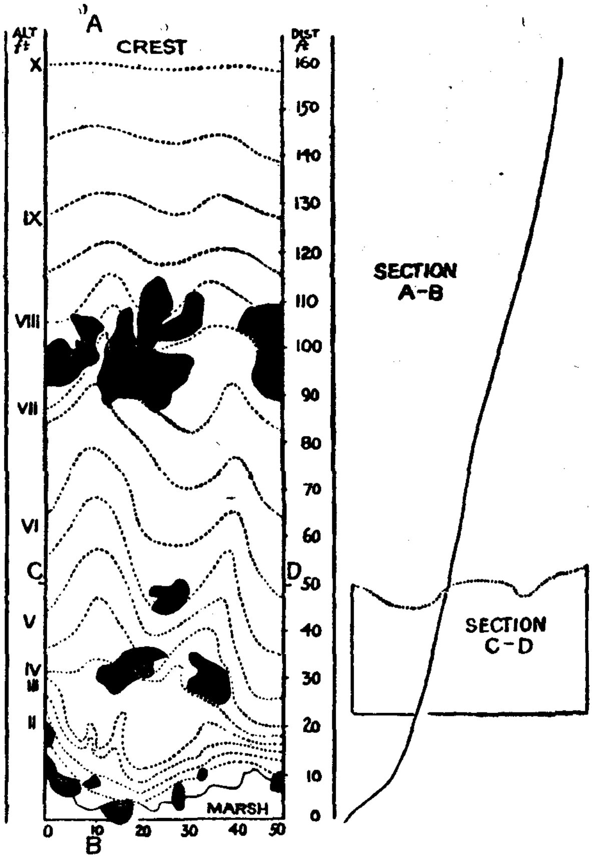


Fig. 27.—Contoured Chart of a Strip, 50 feet wide, of Blakeney Main Beach from the Crest (above) to the Marsh (in front)

The three *Suæda fruticosa* zones (black) cross the chart horizontally. The contours (broken lines) are drawn for every half-foot, the heights above the average level of the marsh being given in the left-hand column (roman figures). The horizontal distances from the marsh are given in the right-hand column. To the right of the main diagram a profile of the bank section A–B is given (vertical factor x5). Lower down on the right the section C–D is plotted showing the two gullies cut across.

ertain knowledge, and for ten years prior to 1907 in all probaility, no shingle travelled by the gully shown. When at ength, in 1912, after a probable interval of fifteen years, the

mechanism was once more brought into play, the line of travel was that followed on the previous occasion.

Apart from the gullies, which pick out the gaps in the successive zones of bushes and link them together, the bushes tend to raise the beach level on their crestward side by obstructing the movement of and holding such shingle as reaches them—clearly shown in the profile represented in fig. 29.

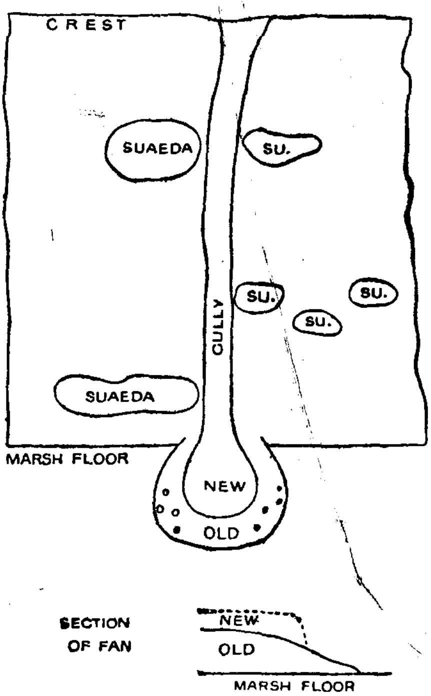


Fig. 28.—Diagram showing Permanence of Dynamic Lines after a Long Interval

The old gully, which passes between the Suæda bushes and which in 1897 discharged the fan marked "old", served again in 1912 to bring new shingle to the selfsame spot. The smaller figure below is a section showing the newly brought shingle overlying the old: note that the edge of the former lies at a steeper angle than the latter. The small circles on the old fan are young Suædas that have established during the period of dormancy.

This raising of level is generally accompanied by a partial burying and prostration of the shoots, and these in their turn respond by active rejuvenescence in the manner already described (p. 104). In this connection it may be pointed out that the more a Suæda bush is shingled over the better adapted does it become to resist the passage of shingle. For by continual development of fresh laterals the total number of shoots standing vertically, per unit of area, is greatly increased, with corresponding improvement of the mechanism as an accretor of shingle. Where shingle is mobile, main axes or branches are not permitted to project for indefinite periods above the ground. Consequently a bush high up on the beach, though lineally descended by vegetative continuity from a seedling dating back perhaps

hundreds of years, may exhibit no shoot thicker than a pen-holder. In this respect the plants of dormant ground, with their thick stems, stand in marked contrast (cf. p. 104).

Before passing on to the subject of the planting of beaches, there are two matters of the greatest importance to the welfare of shingle plants that demand some notice. They are:—

(1) The origin and distribution of plant food or humus in the shingle; and
(2) The water problem.

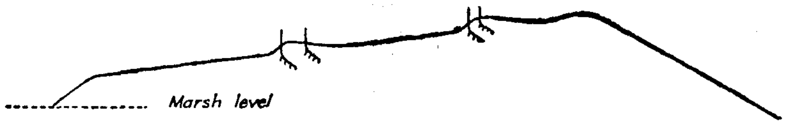


Fig. 29.—Profile of Blakeney Main Beach, showing how the Suæda Bushes cause a heaping up of the Shingle

The Humus of Shingle.—Important to the subject of beach planting is the source from which certain indispensable elements of plant food are derived. A heap of water-worn pebbles without additions is a sterile and inhospitable substratum upon which luxuriant vegetation could not arise. This character of shingle is manifest in the case of apposition beaches—areas of shingle cut off from the sea (cf. p. 89)—which are dependent on their own resources for the humus which accumulates in the interstices. In these beaches (which are dormant) the pioneer plants are chiefly crustaceous lichens. It is by the washing down of the products of disintegration of these that the beginnings of a vegetable mould accumulate, and the way prepared for the establishment of higher plants.

Beaches of the spit-and-bar type, fronted by the open sea, and backed by a tidal estuary or lagoon, receive humus from two sources. From the sea comes ocean drift consisting of seaweeds, zoophytes, bits of wood, corks, and other flotsam and jetsam. These are left high on the beach, and are scattered by the winds over the crest and higher levels of the lee slope. They are met with in all stages of disintegration, and are readily assimilated by the open-textured shingle.

Of much greater importance is the drift from the salt marshes or backwater left at or near the foot of the leeward slope of the beach. This consists not merely of blankets of matted algæ (Enteromorpha, &c.), but of everything on the marshes and mud flats that can be swept up by the tides. Conspicuous components are the leaves and stalks of halophytes (especially *Obione portulacoides*), the dung of rabbits which browse on the marsh, the carcasses of small crabs and other animals which perish, the rhizomes and leaves of Zostera. The total amount of drift available is simply prodigious. Whilst mainly it carpets the foot of the lee slope, occasional high spring tides tend to raise the drift to a somewhat higher level. Once deposited, the drift in time becomes buried in the beach by the slipping of the shingle; in this way there is continuous interstratification of drift and shingle. The process being always at work, the lower parts of the bank become thoroughly permeated with humus. Hence the mechanism by which such a beach slowly advances in the landward direction, also ensures the fertility of its soil.

Drift, however, is not mere organic matter; it is also the great agency by which seeds are brought to the bank—the seeds of the plants which establish themselves upon it—and it is under the protection of the drift that they germinate. Thus it comes about that a lesser amount of humus is available for the upper levels of a beach from the ocean drift, and a much greater amount for its lower levels derived from the marshes on the lee side. The utilization of this low-level drift falls to the lot of plants arising from seed from the drift line. If we take the case of *Suæda fruticosa* already described, it is evident that not only do the young plants on establishment directly enjoy this source of humus, but further, that as these bushes gradually ascend to higher levels they take with them a portion of the food derived from this source (cf. p. 106). As a result of constant shingling over Suæda grows through to a higher level, and with the progressive disintegration of the deeper-seated parts of its rhizome, these food matters pass once more into the shingle, and are available for the Suæda and for such other plants as are able to establish in the surface layers of the beach. Thus we have not only a circulation of combined nitrogen from

the beach to the plant and from the plant to the beach again, but also an actual migration of combined nitrogen from lower to higher levels.

The subjoined table, which exhibits the results of a number of analyses[1] of the top nine inches of soil, shows the superior richness in nitrogen of the ground occupied by Suæda over that round about. The samples were collected from an outer zone 12 feet 6 inches from the centre of a Suæda bush high up on the Blakeney Bank, from a middle zone 4 feet 6 inches distant, and from the area of the bush itself. The results were as follows:—

Position of Samples.	Organic Matter per cent.	Nitrogen (Ammonia and Nitrates) Pts. per Mill.
Outer zone (mean of 4 determinations) ...	1.07	2.35
Middle zone (mean of 4 determinations) ...	1.4	3.2
Area of bush (mean of 5 determinations) ...	2.7	5.1

Other analyses of shingle from the trough and sides of gullies of transport in the neighbourhood showed the organic matter present to be practically nil.

Whilst the great majority of Suæda bushes on the Blakeney Bank have been derived from plants which established originally in the drift line at the foot of the bank, a certain number[2] of seedlings establish directly at higher levels, and even on the crest itself. Observation of several of these continued over a period of seven years shows that, whilst for rapidity of growth they cannot compare with drift-derived specimens, they none the less hold their own and make sturdy plants.

The importance of constant supplies of drift from the landward side in promoting the establishment of vegetation on a beach is emphasized by the great sterility of those stretches of the Blakeney and other beaches which are encumbered with

[1] Made by Dr. H. B. Hutchinson of the Rothamsted Laboratory, who gives us permission to use his results.

[2] About fifty such plants were discovered on a mile-and-three-quarters stretch of the bank.

sand dunes. Dunes usually occur well behind the crest, and their presence prevents the drift from the marshes reaching the shingle. The same result follows when the salt marshes under the lee of a shingle spit are diked off and the tidal waters excluded. The drift no longer circulates, and the bank is starved of its normal food. Such stretches of beach become increasingly sterile, and at the same time more mobile—with tendency to encroach on the diked marshes (cf. App. VI, p. 270).

The Water Problem.—The lower zones of littoral shingle beaches are bathed by the sea, the water in the interstices of the shingle is salt, and the vegetation is necessarily halophytic. Higher up, however, the majority of the plants are non-halophytes, and several of them, if wetted by spray from the sea, are liable to be killed (cf. p. 98). At the same time true halophytes, like Suæda, for instance, thrive perfectly at a level well above tide-marks. The water in the upper part of a shingle beach is fresh and not salt; it is also copious in amount. Moreover, it seems to be inexhaustible. One of the writers of this book visited numerous shingle beaches in the south of England during the autumn of 1911, the year of the famous drought. Though the mainland near by was for the most part completely parched up, no traces were found of any of the shingle vegetations suffering from drought; on the Chesil sheep were browsing (Plate IX, 3, p. 96). As it is difficult to account for these supplies of fresh water as conserved rainfall, it has been conjectured that perhaps an internal formation of dew may take place.[1] In any case, it is remarkable that the water of shingle should remain fresh, for it undoubtedly rests on a salt-water table, and with it rises and falls with the advent of the spring and neap tides, respectively. The matter requires further investigation. The same suggestion has also been made in connection with sand dunes.[2]

The volume of supplies of fresh water in the sand dunes of Holland is so great that it is the source of the water supply

[1] F. W. Oliver, "The Shingle Beach as a Plant Habitat", *New Phytologist*, Vol. XI, p. 98; T. G. Hill and J. A. Hanley, "The Structure and Water Content of Shingle Beaches", *Journal of Ecology*, Vol. II, p. 35.

[2] A. Jentzsch, in Gerhardt's *Dunenbau*, Berlin, 1900; P. Olsson-Seffer, "Hydrodynamic Factors", *New Phytologist*, Vol. VIII, p. 43.

of the city of Amsterdam. It has been demonstrated that the rainfall of the sand dunes of Holland is greater than that of any other portion of the country. The balance of pressures between the freshwater zone and that of the underlying salt-water zone has to be carefully studied, as should the fresh-water seal be broken by severe pumping at great depths, the water supply of Amsterdam would be imperilled.[1]

The freshness of the water and its inexhaustible amount are of importance to the subject-matter of the next section of this chapter, in that fear of water exhaustion in planting up beaches need not be entertained; whilst, as the majority of wild beach plants are non-halophytic, a vastly wider range of plants is available for selection than would be the case if tolerance of salt water were a necessary condition.

The Planting of Shingle Beaches.—The object considered here in planting beaches is that of retarding or arresting the landward movement of shingle spits and other similar formations. The function is perfectly analogous to that discharged by Psamma on a littoral dune, except, of course, that the materials are wind-borne in the latter case.

In what may be termed a normal case the beach is liable from time to time to overflow by storm waves, so that shingle is thrown over from the face, or the crest is lowered, and the shingle carried down the slope to the leeward edge (as illustrated, for instance, in fig. 22, p. 95, and fig. 28, p. 109). Protection such as we contemplate is required in the case of beaches, the landward advance of which is liable to obstruct navigation or drainage channels, to drift over reclaimed marshes, as well as in the increasing number of cases in which municipal works of various kinds have been erected on the beach itself on account of cheapness of site, or where residential "bungalow towns" have sprung up in obedience to the modern demand for fresh air and "the simple life". It will be understood that the protection by vegetation considered here is solely from on-shore gales. The control of the along-shore drift of shingle, on the other hand, lies at present outside the province of the maritime

[1] "The Winning of Coastal Lands in Holland" (A. E. Carey), *Proc. Inst. C. E.*, Vol. CLXXXIV, pp. 1–73.

forester, and must be dealt with by means of groynes and similar constructions.

It is, of course, perfectly evident from inspection of spontaneously vegetated beaches that Nature alone does not carry through the operation of planting densely or systematically enough to satisfy the requirements here laid down. At the same time Nature carries the matter sufficiently far to indicate clearly what remains to be done. In the preceding sections, the part which vegetation has to play in arresting beach travel has been fully emphasized. When waves sweep up and a beach is overwhelmed, this is the cumulative result of a series of waves, each of which pares off and transports a thin surface layer (cf. fig. 22, p. 95). The task imposed on vegetation is thus:—

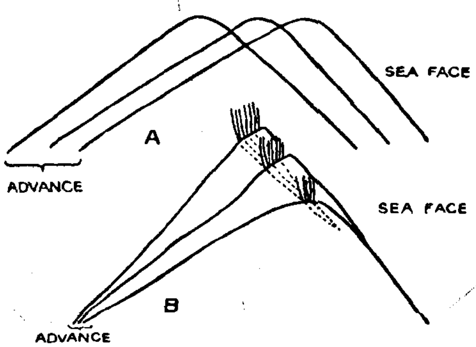


Fig. 30.—Diagrams illustrating effect on Profile and Landward Advance of Planting Crest of Beach with Suæda

A, The unplanted condition; B, with Suæda.

(1) To preserve intact the surface layer of the beach, so that the shingle shall not get on the move.

(2) As plants cannot be relied on to clothe the sea face, the vegetation of the crest must have the capacity to catch and hold such shingle as may be thrown up from the front.

Of native plants, *Suæda fruticosa* is marked out as the staple for employment. It forms a dense surface mat when pounded by shingle; it has a capacity for rejuvenescence, especially when buried, and it possesses the inestimable advantage of rapid growth. Suæda propagates rapidly from cuttings and by seed. Moreover, in the seedling stage it is tolerant of both shingling over and exposure. In Britain the plant occurs in Wales, on the south coast of England, and along the east coast

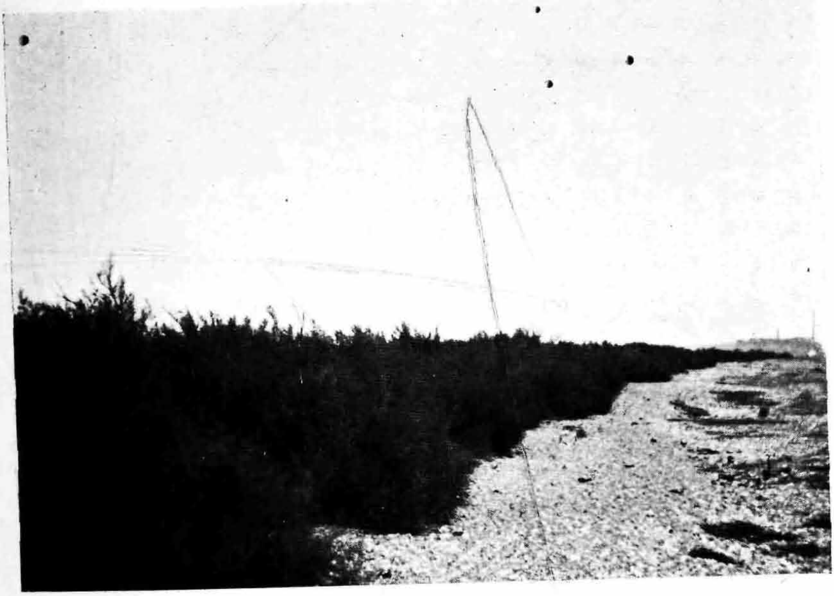
as far north as the Wash. It may be expected to flourish anywhere on our shores, with the possible exception of the north-east coast, where preliminary trials have yet to be made.

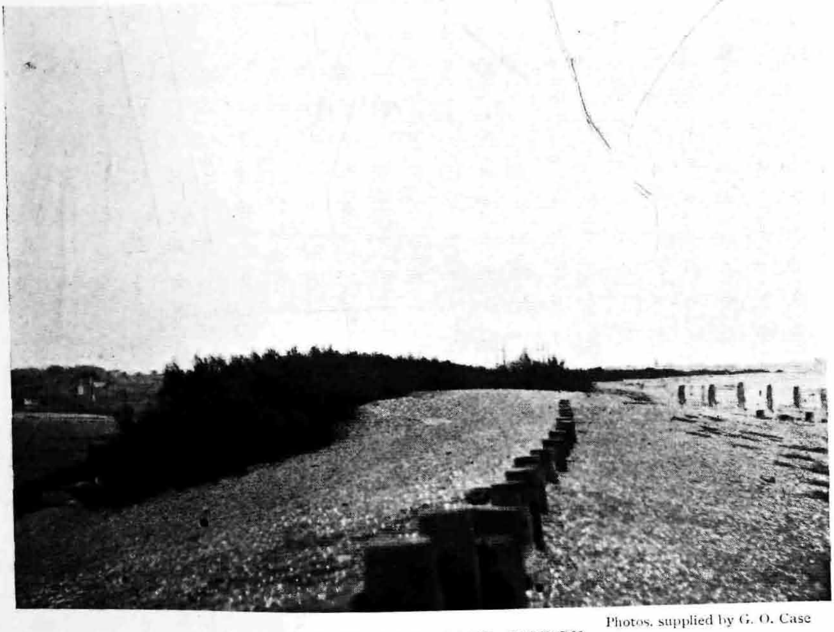
As the primary object in view, in most cases, is the raising of the height of the beach, the planting must be regulated accordingly. We believe that a strip of Suæda, following the crest, and 7 yards wide, should meet all requirements. During the period of establishment the existing gullies on the lee slope by which the water runs off should be fenced across with brushwood at intervals to prevent transport of shingle. When the Suæda has reached its proper growth, and the crest has been raised, the gullies will go out of action automatically.

The crest being the most sterile part of a beach, and deficient in mud and humus, the ground will require preparation before the seed is sown. For this purpose mud should be brought from the marsh behind, spread on the surface to be planted, and beaten in. As seeding is prolific in certain years, and as the seed germinates readily, this method is to be recommended. The seeds should be sown not later than March, about a hundred to the square foot. About 2½ lbs. of seed should be ample for a strip 100 yards long and 7 yards wide. When sown, cover with a mulch collected from the drift line on the marsh. If desired, the plantation may be strengthened by putting in two or three rows of rooted cuttings, one foot apart, but this will add considerably to the labour and expense.

It is expected that the Suædas will be fully established within five years. To give the plantation the best chance of success, it may be desirable to erect to the seaward side of the strip a low temporary breastwork of wood, removable when the Suædas have established. If this be dispensed with as a whole, some protection should be provided along places where the crest drops appreciably—at spots, that is, where waves are prone to come over. There must be no traffic over the treated area, and if a path across the beach to the foreshore is required (either for pedestrians or haulage of boats), it should traverse the belt at an angle oblique to the shore line.

With a view to nursing the Suæda plantation during establishment, it is of advantage to encourage other plants, more





Photos. supplied by G. O. Case

VIEWS OF TAMARISK HEDGE

Holding the Crest of Shingle Beach at Shoreham Harbour. Lower picture is close to the Outlet; the Upper, $\frac{1}{4}$ mile farther east

especially *Rumex trigranulatus* (seed), *Elymus arenarius* (cuttings), *Triticum pungens* (seed), *Lathyrus maritimus* (seed), and where sand is present, *Arenaria peploides.* In front of the Suæda plantation a belt of *Crambe maritima* would be distinctly useful. It will be understood that everything helps, and that the more experiments are made the better for the elaboration of a technique. Of especial value would be trials with shrubby plants, such as *Hippophæ rhamnoides* (Sea Buckthorn), Willows, such as *Salix repens*, *Lycium barbarum* (the "Tea Plant"), &c. The Sea Buckthorn flourishes with us as a dune plant, and it also thrives both in maritime and river shingle. It is important not only as a mechanical agent, but also because (like the Leguminosæ) it is one of the root-nodule plants, with power of fixing free nitrogen, and thus fertilizing the ground. A tried plant in holding shingle is *Tamarix gallica*, and a narrow belt of this should always be planted behind the Suæda, in districts where the climate is favourable, as on the south and west coasts. A splendid example of the successful employment of Tamarix is to be found on the beach opposite Shoreham, just to the east of the outlet of the harbour. These plants were put out some thirty years ago, and developing thick trunks and adequate root grip have materially strengthened the beach (see Plate XI). For the improvement of the amenities of bungalow settlements and the like on shingle no better plant can be used.[1]

During the period of establishment, and with a view to hastening it, the young plantation must from time to time be mulched with a top-dressing of drift from the salt marshes. Eventually this can be discontinued, as the plantation will be self-supporting like a forest.

In contrast with the direct method of planting, a beach can be treated *indirectly* by planting the lee edge, or even the ground parallel to the beach but not yet occupied by it. This method closely approximates to the natural operation of Suæda

[1] In the way of shingle gardening there is no limit to the possibilities. Shingle, humus, and water, in proper combination, form the medium of the now fashionable "Moraine garden". Alpines for the most part are cultivated in this way, whilst the province of maritime shingle awaits exploration.

establishment already described (p. 104). It can be deliberately employed in cases in which a travelling beach can be permitted to advance a distance equal to its own width, and it is the only method available in the case of beaches which are so mobile that they cannot be directly planted. The Northam Pebble Ridge at Westward Ho is probably an example of this last class. Apart from enormous and prohibitive expenditure on engineering constructions, we are disposed to think the only alternative to the loss of this ridge and the ground which it protects is the planting of a tough belt of scrub on the lee side, so that the ridge may there be arrested and permanently fixed, an operation which in the present pioneer phase of this art will require both intelligence and boldness in carrying through.

The planting of the lee side of a beach so that by the time it has sufficiently advanced the crest may be fixed by vegetation is not a policy to be recommended, because it postpones stabilization to an indefinite date, and is liable to beget slackness in the administration. It is best that the crisis should be grappled with by direct methods, even if the conditions are somewhat more exacting. Moreover, one never knows absolutely what is going to happen, and valuable decades may be lost by a Fabian policy.

At the beginning of this section the idea was dismissed that ligneous plants could be employed on the foreshore to serve the purpose of groynes. So far as the sea is concerned, such notions are altogether premature, but on the banks of rapid rivers the "vegetable groyne" has already emerged from the experimental stage. Where the channels of rivers are being improved young trees of the Grey Alder (*Alnus incana*) are planted groyne-wise in rows at right angles to the banks, and the method has proved very successful—e.g. in the case of the River Ticino in the arrest and fixation of shingle. Moreover, as the Alder is another of the plants possessing nitrogen-fixing nodules, a highly beneficent nutritive action on the ground reclaimed is to be expected. (See p. 216.)

A vegetable groyne for the seashore can be hoped for only when a sufficiently massive ligneous plant, tolerant of sea water, can be discovered or bred. The various species of tropical

Mangrove approach in some measure the requirements, but it is hardly to be expected that any of these would acclimatize on our coasts; moreover, they are normally denizens of muddy water rather than shingly shores. Perhaps some day when the production of plants to fulfil definite requirements has become a regular craft, some plant breeder may take up the task.

By dint of persevering and intelligent experiment we have little doubt that the future holds in store further possibilities in the treatment of shingle beaches. Significant in this connection is Calshot Point, opposite Spithead. This shingle spit bears a thicket of Gorse, Broom, Hawthorn, Holly, Dog Rose, and Blackthorn, and among this scrub are solitary well-grown specimens of Corsican Pine and of Holm Oak (*Quercus Ilex*). It is true the spit is washed by relatively tranquil, land-locked waters, so that the exposure is moderated in comparison with the open sea. Still, boldness and skill in combination generally triumph, and we should expect a well-considered attempt at afforesting maritime shingle to succeed.

As regards the treatment of apposition beaches (cf. p. 89), which form great stony wastes at Dungeness, Rye, and Orfordness, we have little doubt they could be converted into forest areas without great difficulty. Being unaware of any experiments on this class of ground, it may be suggested tentatively that *Alnus incana* might be planted as the pioneer, to be followed by such species of Pine as *Pinus Laricio*, *P. nigra*, *P. insignis*, *P. sylvestris*, and by Sycamore, Walnut, Wych Elm, and Holm Oak. Other species should also be tried.

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CHAPTER VIII

Tidal Land Reclamation (Works)

Broadly speaking, the operation of reclaiming riparian and littoral lands may be classified under two headings:—

(*a*) The "inning" of saltings and marshes;
(*b*) The shutting up of breaches in river and sea banks, and the consequent arrest of tidal inundation.

During the long depression from which agriculture in the United Kingdom is now slowly recovering, the former practice has been under a cloud. In Tudor days many schemes of this kind were pushed to fruition, as the number of Acts passed with that object testify. It is probable that the exodus of refugees from the Low Countries, many of them specially skilled in this art, stimulated the popular demand. Moreover, landowners were in Queen Elizabeth's day compelled by law to reside a large part of each year on their properties, and their energies were consequently devoted to the means of increasing the cultivable area of their estates.

Under the second category of works falls a class of undertaking peculiarly prolific in casualty. It involves operations in which, often over a long frontage, the searching test of hydrostatic pressure is applied. From a weak spot in a half-consolidated embankment, from a few yards of porous filling or badly-punned clay has frequently started a "wash-out" when success was nearly achieved, necessitating a resumption of operations *de novo*. Casualties are apt to be left unrecorded, whereas they are the school of success. Perhaps in some degree to this cause may be traced the fact that literature descriptive of such undertakings is scanty.

Inning Saltings.—This art is coeval with civilization, and in Great Britain goes back at least to the Roman occupation. In deliberateness it approximates to the primitive processes of growth. The richest agricultural lands are often by this means evolved. Many bold schemes of land reclamation have brought fortune in their wake; in other cases, owing to an insufficient height standard of walls or badly designed drainage, large expenditure has been for many years unremunerative or even abortive.

The primitive method of reclaiming slob land is still in vogue—i.e. warping. The process of warping is that of permitting or assisting the tidal water carrying silt in suspension to flow, with as little disturbance as possible, over a tract of low-lying land, when, by inappreciable degrees, new land comes into being as the result of deposit. Sometimes low embankments of earth or faggots are adopted to check the exodus of the silt and quicken the process of deposit. The land so formed is often agriculturally extremely valuable. The famous root-growing lands of Lincolnshire have been largely created under this system. Frequently gorse is used for forming the fascines to hold the detrital matter. Where silt carries any considerable proportion of sand, the sand is usually found to be deposited near the source of the alluvium in suspension, as the fine particles of earth travel with the water a much greater distance than the sand. Whereas brick earth in suspension will sink at the rate of about 7 inches per minute, sea sand in the same period will sink about 12 feet. Almost all rivers of low gradient flowing through alluvial lands are heavily charged with detritus, and by simple methods this may be captured for land-making, in the same fashion as deltas are formed. The yield per acre of crops of oats, wheat, and beans from land of this character is exceptionally great, and a sedgy waste may thus be converted into valuable agricultural land. In one case of warp land on the Trent 184 acres of peaty deposit, owing to the ingress and egress of the tide, in three years were raised from 1 to 4 feet in height. At the end of the first season grass seed was sown, in the following year white clover, and cattle were allowed to stray over it. In three to four years the land was ploughed and

immense crops yielded by it, the soil retaining its fertility to an unusual degree. As all the detrital deposit is by natural means reduced to extreme fineness, the soil formed by it becomes exceptionally kindly. Mr. Arthur Young, whose observations on agriculture in England in 1807 are well known, frequently refers to the above method of land reclamation. In one case in Essex he records how a ridge of sea-shells, and subsequently of faggots, had converted a large tract of slob land to agriculture. In Lincolnshire he speaks of 10,000 acres reclaimed in a similar way, and he also mentions the dikes of Southern Holland and others in the marsh-lands adjoining the Fen country, which were probably embanked by the Romans.

The report of the Commissioners of Woods in 1838 on Sunk Island on the Humber is instructive. Of this area 3500 acres of drowned land were leased in 1668 at £5 per annum, the tenant undertaking to embank 100 acres in ten years. He failed to achieve results, and in 1675 a new lease was granted. In 1744, 1560 acres had been embanked. In 1755 a fresh lease was granted, the tenant paying 1000 guineas premium, and in 1771 another lease, when the premium was £1550, and the rent £100 per annum. The Crown ascertained by survey that 2700 acres were fit to embank at a cost of about £9000; the estate was then worth £3400 per annum. The next lease expired in 1833, when the area of farm-land was 5929 acres. The next tenancy was at a capital value of £9140, the tenant agreeing to keep all banks in repair, and to spend £8800 in buildings. At the present time the area reclaimed is 6600 acres, producing a revenue of £10,000 per annum. Up to 1850 the beneficial tenants carried out reclamation; since that date the Office of Woods have themselves done the work. In 1896 they started an extensive scheme of reclamation by means of warping cloughs, an arrangement of lock gates for the purpose of impounding tidal waters and letting it escape gradually, so as to catch its detrital matter and thus expedite accretion. This operation, however, proved a failure, as the enclosing walls did not sustain the weight of water admitted.

Recently attention has been directed by Lord Montagu of Beaulieu to the effect of Spartina grass on the fixation of mud

flats in Southampton Water. This grass spread with rapidity over mud flats extending about twenty-five miles and submerged twice a day by the ordinary tides. The grass commenced to grow in circular patches, which subsequently spread and amalgamated. In so doing it caught the detrital matter and quickly made new land. Specimens from Southampton Water were submitted to the Director of Kew Gardens, who stated that three species of Spartina occur. This grass has the advantage of being serviceable for feeding cattle, and might be used for a variety of purposes (cf. Chap. X, p. 183).

The works commenced in the reign of Charles II for the recovery of drowned lands in the Fen District and in Lincolnshire are notable. It is stated that the Fen area is at the present time sinking at the rate of one inch per annum. There is distinct evidence of subsidence in the Island of Foulness. It is probable that the greater part of the marsh area running northwards from the estuary of the Thames is in some degree sinking, as Ordnance bench marks and level stones fixed within a marsh area are generally unreliable for levelling purposes. In order to ensure accuracy, it is necessary to carry levels back to points on stable land in rear of the marshes.

Further instances of land reclamation in Great Britain could be multiplied. Speaking broadly, it may be said that the kingdom of Holland, comprising 13,000 square miles of some of the best agricultural land in Europe, with a population of 4½ millions, has been evolved by similar operations. The Dutch system may be briefly described as follows:—

The area to be redeemed having slowly accreted up to the stage of rough herbage, it is embanked and ditches are dug inside such banks. An accumulating reservoir is requisite to take discharge at low tide. The tract of land thus roughly cleared is, in effect, a swamp, and ditches are then driven across it so that it resembles a chess-board of land and water. The soil removed from the ditches is spread over the land to be reclaimed, and pumps are set to work to get rid of the superfluous water, the inflow of which is regulated by sluices. By this means a new polder of Dutch land comes into being.

The art of the sea-waller is a survival, and probably has

changed almost as little as that of the shepherd. Old-time names and bases of measurement persist in many districts, so that caution is necessary in accepting local estimates of quantities. The shifting of clay is measured either by the "floor" or by the cubic yard. In different districts, sometimes in close proximity, the unit measurement of the rod varies. The "floor" is 1 square rod a foot deep, and the local measurement of the lineal rod is sometimes 15, sometimes 16½, sometimes 18, and sometimes 20 feet. The "floor" of 400 feet contains about 15 cubic yards, and that of 320 feet about 12 cubic yards, so that care must be exercised to prevent miscalculation.

The nomenclature of the sea bank is worthy of record. The base of the wall is usually termed the "seat", and the body of the wall up to high-water level is called the "main bank". In embankments facing the sea, the crest, up to within a few feet of the summit of the wall, is often called the "outburst bank", and the actual apex is called the "swash bank". On the land side of these banks there is usually a berm slightly inclined towards the ditches. This is called the "foreland", and the main ditch running at the back of the "foreland" is, in most of the Essex districts, termed the "delph". Many other local names are found in different districts. In the West of England the main ditches are termed "reens". Subsidiary ditches are called "rills", the waterways intersecting the saltings being locally called "creeks".

The navvy's run is usually taken at 100 yards, and a good workman will shift 9 cubic yards a day, but the average is more like 6 or 7 cubic yards. One man will store as much as three men can run, and the packing of the spits of earth upon the face of a bank is called "flood flanking". The short piling sometimes used at the foot of banks is 4, 5, or 6 feet in length, and the usual reckoning is that four score of 6-foot piles make a hundred, five score of 5-foot piles, and six score of 4-foot piles. These piles are mostly the toppings of trees, which are sometimes oak, but preferably elm or birch. They are driven in by hand. The re-sodding of the bank consists of the lifting of the top spit of grass and replacing this as the surface of the new work.

The front of the bank facing exposure to tidal waters is laid

out to a flat angle. Where sea exposure is considerable, the slope of the wall should approximate to that of the sea beaches in the vicinity. For estuarial embankments it is usual for the front slope to be at an inclination of 1 in 2, and the back of the wall 1½ to 1. In the reclamation bank on the south side of the Ribble, the slopes of the upper half were 2 to 1, and of the lower half 5 to 1. In Lincolnshire and on the Wash the front slope is generally 5 to 1. Frontages to rivers or creeks where exposure is not extreme will stand quite well at 2 to 1, but where heavy sea-bursts are anticipated it is better to reduce the slope to 3, 4, or 5 to 1. The usual width of the top of the bank is 3 feet, sometimes 4 feet. In positions of exposure it is often necessary to pile the front edge of the wall by means of short piling, as described above. It used to be common practice to drive piling in successive rows and fill the space between with stone pitching; these spaces were called "rooms". This practice is, however, not to be commended. It is difficult to secure the consolidation of the stone pitching up to a line of pile stumps, and the timber when soaked in water changes its volume and is subject to decay. The consequence is that the stone-work becomes loosened and a heavy run of sea or tide may quickly dislodge a portion of it, when the stone pitching lying above such breach slips, and the result is a dangerous cavity in the wall, which is exposed down to the clay. The usual practice in southern England is to pitch the surface of the clay with chalk, and a depth of 8 inches is a common thickness. Above the chalk stone pitching, generally 12 inches thick, is used; ragstone is mainly used in the south. Rendering this stone-work rigid is termed "keying up" the bank. Most exposed sea-walling requires keying up once a year, and this consists of adjustment and driving home fresh stone-work. It frequently happens that a stone-dressed surface is not sufficiently stable to stand the heavy blows of the sea, and in localities where the run of the water is extreme such stone-work is sometimes grouted in cement, finished with a smooth surface. This practice has the disadvantage that in heavy gales the seas run up the bank and the spray is carried over the land in rear by the wind.

On the Dutch coast practice differs considerably from the English. The Dutch seaboard for the most part consists of wide sandy plateaux, lying at an easy gradient, and the problem is to check the scend of the water, the momentum of the waves being largely absorbed by the flat foreshore. The difficulty in many Dutch undertakings is the precarious nature of the foundations of sea-walls. Many miles of sea-walling in Holland rest upon unstable clay embankments, and the result is frequent casualties, called "falls". If by underwater denudation the sea front becomes mobile, the earth pressure at half-flood sets the mass of the wall in motion. It thus happens that large areas, sometimes amounting to hundreds of acres, slide bodily down into the bed of the sea. These casualties resemble the effect of earthquake shock, and are followed by a great tidal wave sweeping landwards, and thus completing the devastation of the polder in rear of the sea-wall.

The standard Dutch practice has hitherto been the use of basalt stone facing. This was brought down the Rhine from the Andernach district. Formerly a limestone from Dornik was used. The cost of facing Dutch dams was about 16*s*. per square yard, the basalt representing about 9*s*. 9*d*. of this sum. The method usually adopted is as follows:—

The slope of the wall is carefully graded with clay to leave a finished surface. This surface is then thatched with straw or rushes, and the workman forces the sheaves of straw into the clay up and down the wall and at right angles to it. The covering of straw or rushes is about 1 inch thick, and a labourer will lay 70 yards in a day, the cost of which is slightly over 2*d*. per square yard. Over the straw brick tiling 2 inches thick is laid; above the tiling random broken brick, and the surface is formed of basalt pitching 15 or 16 inches thick, packed with brick. It will be seen that the art of the sea-waller in Holland is highly expert. The sums expended are extreme. On the Osse breakwater, in the Island of Schouwen, the cost of the basalt pitching was £3. 12*s*. per lineal foot.

In the Dutch practice matting or fascine work is largely employed. In the lightest matting branches of willow 10 to 12 feet long, freshly cut, are laid on the slope to be protected,

and these are placed to break joint, the butt ends being generally at the shallower end. Timber pegs are then driven through the mats in horizontal rows, about 3 feet apart fore and aft and 1 foot transversely. A hurdle is then twined 'round the holding-down pegs for a height of 6 or 8 inches, and such hurdles are frequently held in position by timber pegs. Mattresses of this character can be ballasted with stone up to 1 cwt. per square foot. For more exposed work wiepen are used. These consist of long faggots or fascines, 4 to 6 inches in diameter, bound with osier twigs every 12 inches. The mattress so formed may be of any length, as the faggots are arranged to break joint,

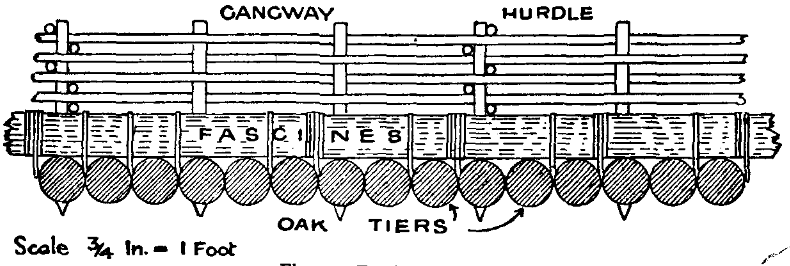


Fig. 31.—Fascine Mattresses

and the spinning of such wiepen is brought to a high art by Dutch foreshore workers. They have to be sufficiently strong not to disintegrate, and yet sufficiently pliant to accommodate themselves to the unevenness of the bed of the channel. Such wiepen may be ballasted 8 or 9 inches thick, and will carry 3 feet of stone above the ballast. They are pegged down to prevent their slipping down the slope on which they lie.

As a protection against falls, huge mattresses[1] (zinkstukken) are employed, and such rafts, formed mostly of osier boughs interwoven, are floated to the site to be protected (fig. 31). They consist of successive tiers of hurdles, preferably of oak, the lower tier running transversely and the second tier longitudinally, and these are bound together with osier twigs and at the corners lashed with tarred rope. Sometimes they have a

[1] "Sea-coast Defence Works in the Netherlands" (H. T. H. Siccama), *Proc. Inst. C. E.*, Vol. CLXIV, p. 378.

gangway hurdle surrounding them. They can be towed to the desired position in the manner of a lumber raft. When secured in the desired position, they are surrounded by barges laden with stone, and at a given signal the stone is cast on to the mattress, the art being to ensure that it shall sink uniformly in its desired location. As the raft sags it should take the ground first at the centre, and when it is completely in position rip-rap stone is thrown to cover it and prevent its breaking up. These rafts sometimes measure 80 feet by 400 feet, and the art of their employment is essentially Dutch, but the practice was adopted by Captain Eads in the works at the mouth of the Mississippi River. The entrance channel of the river was projected into the Gulf of Mexico by means of jetties supported on similar fascine work. The east jetty had a length of 11,800 feet, and the west jetty a length of 7800 feet; the scour so induced, assisted by dredging, has resulted in a channel depth of 30 feet.

De Muralt has employed concrete mattresses in lieu of the old type of fascine. These consist of concrete slabs about 1 yard square and 5 inches thick. They are laid out on a low-water flat, secured together with iron links. A pontoon is floated over them at high tide, and by means of cable attachments worked from windlasses the entire mattress is lifted, the method of lifting ensuring that its formation is not distorted when over the desired location; it is then lowered on the sea bed, being held uniformly and horizontally. It is claimed that this arrangement is not only more efficient but cheaper than the old system, and that the concrete mattress can be laid on a sloping as readily as on a level sea bed.

In modern Dutch practice the de Muralt system of plating embankments is a novelty. The system is largely in use in Holland, and has been adopted on an extensive scale in Great Britain. De Muralt employs two methods. In the lighter system (fig. 32) concrete tiles about 16 inches square and 2¼ inches thick are used. The edges of these are rebated, so that the tiles interlock. The former practice was through a hole in the centre of the tile to drive a concrete pin to fix the slab in position. It has been found, however, that the heads of

these pins got broken off, either by accident or intent, and the modern practice is to work a hole in the clay with bars and ram the cavity so formed full of concrete. This forms an irregular-shaped attachment between the tile and the clay bed. The advantages of this system are its cheapness and the fact that

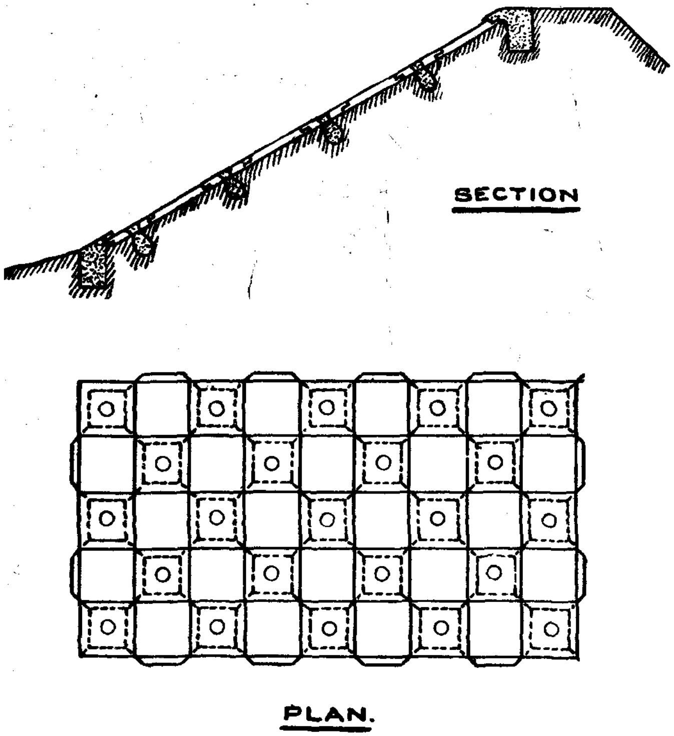


Fig. 32.—De Muralt Concrete Plating of Embankments (Light Type)

it is elastic. Slight movements in the bank do not affect it, owing to its lack of rigidity. The cost under normal conditions, including the dressing of the bank to receive the slabs, is about 7*s*. to 7*s*. 6*d*. a square yard. The cost of stone and chalk having materially increased, this type of the de Muralt system is probably somewhat cheaper than current English standard methods. It is available only in positions of lesser exposure, and the slabbing has to be periodically overhauled, as vegetation is apt

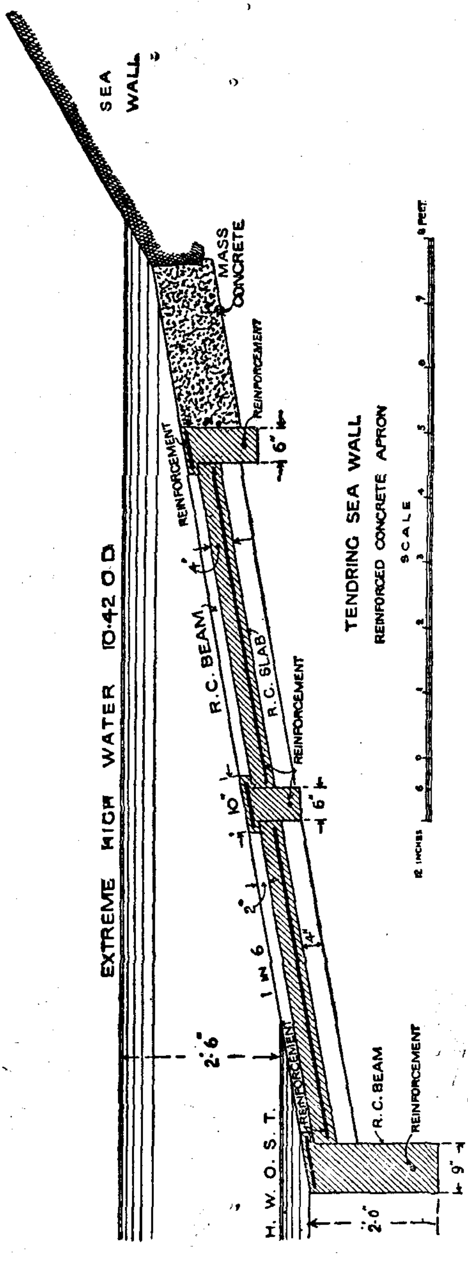


Fig. 33.—De Muralt Concrete Covering of Embankments (Heavy Type)

to force its way between the joints of the slabs and displace them, causing upheaval of the covering of a bank.

In the heavier type of defence the slabbing is deposited *in situ*. The concrete slabs, with a stepped face, are laid on the bank, and between the slabs the bank is *trenched*. In the trenches steel reinforcement is placed and embedded in mass concrete. The beams thus built hold down the slabs, and form, as it were, casements for them. The slabs themselves are reinforced. This system is suitable for positions of greater exposure. Fig. 33 shows its adoption to form the apron of a sea-wall on the Essex coast. It will be noted that special expansion joints are used to prevent cracking of the slabbing. The positions of these joints have to be carefully

adjusted to the requirements of the work. The cost of this heavier type of protection in Holland is about 16*s*. per yard super. Another novelty introduced by de Muralt is the use of reinforced concrete coamings or bulwarks at the crest of a wall (fig. 34). This is an expedient which, on the Dutch coast, is efficient for heightening the sea embankment at small cost.

The regulation of the discharge of land water is effected by a system of watercourses and sluices. Each locality has to be studied in respect of its local conditions of rainfall and the agricultural or industrial requirements of the land affected.

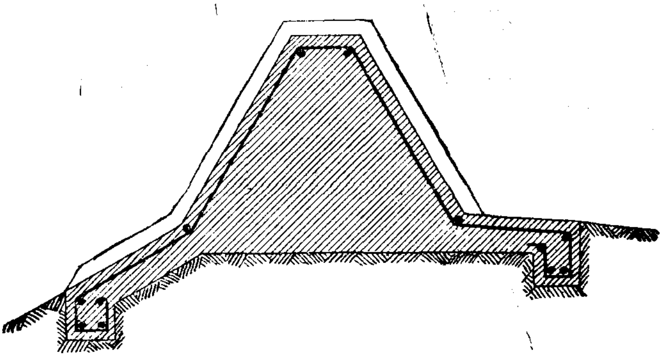


Fig. 34.—Reinforced Concrete Coaming for Sea-walls

Where land enclosed by a sea or river wall is devoted exclusively to agriculture, a considerable amount of water is often held in the drainage ditches to supply cattle or serve the crops or herbage. Where in rear of a sea-wall the land is devoted to industrial purposes, the usual requirement is to get rid of surface water with the greatest possible rapidity. The arterial drainage should provide for the control of exceptional floods, to prevent the land from becoming waterlogged. Where tropical conditions of rainfall exist, this is a matter which often taxes not only the land drainage system, but also the river channels which carry off flood water.

The summit level of the sea-walls on the estuary of the Thames is 18 O.D., and on the Lincolnshire coast the standard is 20 O.D. On the Dutch coast defensive dams are carried to a height of 20.7 O.D. The conditions of disposal of land water

differ in England and Holland owing to the generally greater range of tide in England, and by reason of the fact that the inland waters of Holland are kept at an artificial level by means of a vast system of pumping. Canal and inland waters are by law maintained at artificial heights, and one object of this is that an immense drainage reservoir for flood water in case of inundation is thus secured. There is no fixed general water-level throughout Holland, but its regulation is under the control of a Government Department, who study the national requirements and maintain the balance with great skill. If a really serious breach in the defences of Holland took place, such, for instance, as the giving way of the Helder Dam, it is quite conceivable that practically the whole country might be submerged.

The level of the main outlet drainage sluice of a marsh, if fixed too low, is only operative for a short period at extreme low water; if fixed too high, it ceases to operate too soon. The broad standard rule for the level of the sluice outfall may be stated as a level such that the drainage can get away freely from about half-ebb to half-flood. The gutters which carry off the effluent water are sometimes of brick or concrete, with elm flaps, more frequently iron pipes with grids and tidal flaps. After a period of exceptional flood it is the duty of the marsh bailiff in charge of a given level to see that the tidal flaps are lifted to allow the land water to get away with the least possible delay, and conversely, in periods of drought, it is sometimes necessary to hold back a portion of the land water and prevent its escape. Fig. 35 shows the design of a standard sluice on Foulness Island.

The materials of which sea-walls are built average about twice the weight of water, unit for unit, but the design of a sea-wall based merely on a diagram of forces would be inadequate and precarious. The casualty element looms large in this class of work. Clay is the most resistant material for sea and river embankments, but obviously on the score of expense local materials must perforce be used. Some of the walls reared in the Fen country, probably by the Romans, are in effect artificial sand dunes, with some admixture of silty mud. Their designers trusted to bulk and height to effect their purpose, and the

system of *corvée* labour was doubtless adopted by the conquerors. Primarily in a sea-wall dead weight is matched against momentum. Walls, if properly looked after, do not fail by direct breaching blows. If percolation takes place under the seat of a wall it is usually noticeable, and can be arrested in time. The surest manner of effecting this is to dig a trench on the landward side and fill it with well-rammed clay puddle. In the majority of instances in which breaching has taken place in sea-walls, such breaching has been caused by insufficient height. If a wall is supported in such a position that heavy spray passes over its crest, this may quite easily set up scour at the back, and a comparatively small run of water scoring its way down the back of a wall, especially if the wall be newly constructed, will sometimes so weaken its section that it gives way. The effect of a stream of water passing over a wall in this manner is to cause a rill down its inward slope, and this sets up weir action at the toe of the wall. By slow degrees the material of which the wall is composed oozes away into a flat slope, and the final result is a breach.

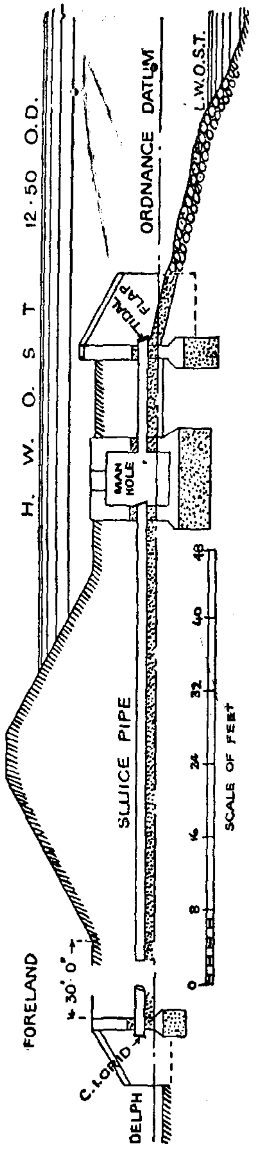


Fig. 35.—Cross-section Standard Sluice, Foulness

It is frequently the case where a line of river walling is threatened with erosion from some local cause that it is a cheaper expedient to abandon the attempt to maintain the length of main wall in question, and to construct behind it what is termed an inset wall, i.e. a horseshoe embankment. Great care has to be exercised in the location of such an embankment,

so as to place it on the most stable ground available. These embankments are usually constructed so as to form a rectangular recess set back from the original line. Where the new inset wall parallel to the river runs into the two right-angled walls from the river, flat curves should be laid out so that, when the works are completed, all corners are eased off. Inset walls require to be stone-pitched on the river or sea side, as, in the event of a breach in the front wall, a sudden and dangerous rush of water may result.

In any critical operation upon a sea-wall, such, for instance, as the reconstruction or repair of a sluice, it is essential as a preliminary to build on the inside of the wall a temporary horse-shoe embankment, isolating that part of the wall which will be affected by the works, and care should be taken to bond the temporary earthwork well into the permanent earthwork of the wall. In carrying out a new sluice it is, moreover, necessary to execute the work in short lengths, and make good the bank as the work proceeds, so that at no point in the operations is the water from the sea or river allowed to pass through to the rear of the wall.

Another very important factor is to choose the most favourable season for carrying out such work. According to the countryman's phrase, in the late spring and early summer the "bird tides" occur. In April and May, when the nesting season is timed, an absence of severe weather conditions usually prevails. The tides as a rule are then low, and wind conditions moderate. This season is, therefore, a favourable period for carrying out works of this character, involving risks to a level. In respect of the re-dressing of the slopes of a sea-wall and the raising of it to its standard height, the months of October and November are the most favourable. After the heat and drought of summer walls are apt to crack, and dangerous fissures may thus be produced. The traffic along the crest of a sea-wall, the passage of cattle and sheep, and its normal settlement due to weather conditions cause some subsidence of the apex of a wall, which has periodically to be made good, and at the same time the slopes, which may have become deformed, require trueing to the proper gradient. All this is best done during the period

of the autumn rains, when the new and the old work can be blended and amalgamated, and also hands are freed from harvest operations.

One matter of moment is, in the reinforcement of the slope of a river wall, to restore the turf and carefully ram this down with iron-shod rammers. When the turfing has been thus relaid it is usual to dress the surface down with silt or slob to fill up the interstices, and this operation is termed "sludging". Where walls are constructed on a clay foreshore, the clay should always be taken from the landward side of the wall, as the material on the sea or river side is usually of a silty and sloppy description, and liable to be washed out by heavy rains. Great care should be exercised to find the best localities for clay. It frequently happens that clay is patchy, running in veins. It is in this respect that the art of the sea-waller comes into play. He has acquired an intuitive appreciation of the spots where the best material can be obtained, and picks them out unhesitatingly. The clay taken in this manner should not be less than 30 feet away from the inner toe of the wall. Where peat has to be employed, such material packs close, but is somewhat light. It is therefore necessary heavily to stone the surface of a sea-wall constructed of peat. The vegetable constituents of a peat bed remain constant for many years, and the transition into black peat is a chemical process requiring hundreds of years for its consummation. In the stone countries concrete is the proper material for sea-walling, as obviously an embankment of stone débris will not resist percolation. Embankments of gravel, if dressed with a water-resisting argillaceous covering, may be quite effective, but rules of height and mass have to be more liberally interpreted when a gravelly material is employed. The most treacherous material is that which, when in a wet state, retains its protective appearance, but under a hot sun or in a strong wind is liable to disintegration. A light silty slob is quite serviceable as a filler of interstices, but almost useless for the purposes of an embankment where the conditions are at all severe.

The rapidity with which vegetation springs up on a new bank is amazing. It is a sound rule, after the seed of the

protective plants has dropped, each year to have the walls cleared of coarse herbage. This may be done either with the scythe and reaping-hook, or by fire. If the walls are stripped in this manner every season the result is a growth of a close tenacious mat of vegetation, which acts as an admirable protection. If the vegetation be allowed to grow rank and rampant, the result is that light and air cannot penetrate properly to the bank, and rough bushes alternate with bald and unprotected patches of embankment. This is a double disadvantage, as if the larger shrubs are uprooted they leave dangerous cavities in the bank. No trees or shrubs should be allowed on a sea bank. Every autumn, therefore, the surface of the bank should be scarified of superabundant vegetation, so that the minute vegetable growths may have a chance of establishing themselves and forming a dense sward. The travel of sheep consolidates a bank, but horses and cattle should, if possible, be kept away, as they tear down the edges of a bank and their hoof tracks leave dangerous pockets for disintegration. Rats and rabbits are the bane of sea-walls, and a merciless warfare has to be carried on against them, as they are the frequent cause of serious casualty.

In some districts, where the ground is of a silty character, the backs of walls are planted with lucerne, but from the protective point of view species of Triticum grass and the more wiry maritime plants are the most effective. One of the most dangerous practices is the construction of the delph too near the toe of the wall. This renders the ground sodden and may set up dangerous subsidence. The width of the foreland should be 30 feet, and the foreland should be laid at an inclination of 1½ inches in the foot to the delph, so that drainage may freely escape into the ditches. It must be borne in mind that all freshly-constructed earthwork shrinks and settles. It is therefore advisable, when a wall is retopped, to form the apex to a level 6 inches above standard height. On a well-constructed wall, and barring casualty, a wall so topped will in two or three years have settled to standard height and will probably not require serious repair for several years longer.

It is hardly necessary to say that in no department of engi-

neering work is the "stitch in time" of greater economy than in works of this class. Every sea-wall should be walked over once a week by the marsh bailiff. Should there be any indication of breaching, instant protective measures must be taken. An apparently trifling weakness in a bank, if neglected so that a breach occurs, may result in the loss of thousands of pounds and the deterioration of the land in rear for agricultural purposes for at least fourteen or fifteen years.

Statements of costs are so local that they are of little service. In the Essex district the normal covering of a clay bank with chalk and ragstone, including the dressing of the bank to receive these, costs about 7*s.* per yard super.

Turning to the question of the accretion on the river side of an embankment, such accretion is usually called the "warp". The construction of a series of groynes approximately at right angles to a river bank was an expedient formerly much in vogue. The argument applied in its favour was that the system resembles the groyning of a seashore, but such contention is fallacious. A river foreshore differs from a sea foreshore by reason of the fact that the accretion which it is desired to capture in the former case is the alluvium borne by the river to the sea. The material in suspension brought in by the sea is mostly of a sandy character and is quickly precipitated, whereas the condition on a seashore is that of the oscillation of the foreshore materials (shingle or sand) alternately up and down the coast-line under the action of the wind waves. Moreover, the division of a river bank into compartments by means of projecting spurs is in the main itself productive of scour. This action was well exemplified on the frontage to the River Roach in the Island of Foulness. At this spot a horseshoe embankment had been constructed, as the main bank was threatened. A short length of the main bank then gave way, and the result was that the alternate filling and emptying of the basin between the original embankment and the horseshoe embankment so denuded the new line of foreshore that it had to be protected with heavy stone pitching. In a lesser degree the same kind of action takes place between groynes run out across a river foreshore. This is thus broken up into a series of compart-

ments, and the result is scouring currents tending to drag the alluvial material down into the stream. The material so dragged down may become an obstruction which has subsequently to be dredged away. In special localities, where, owing to a sharp twist in the line of a river, erosion of the bank may be anticipated, it is sometimes permissible to run out an isolated jetty to accumulate material in a special spot, but, as a system, the groyning of a river frontage is one which may quite possibly do much harm, the effects of which for good are strictly local.

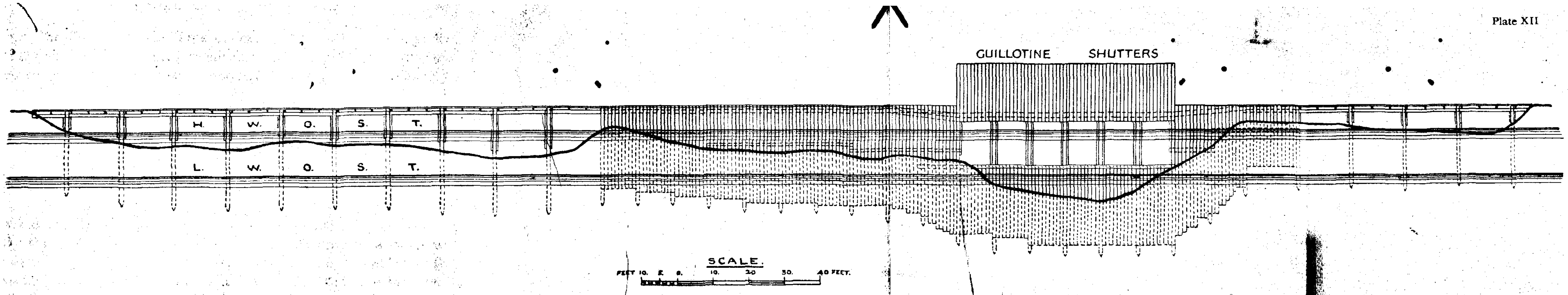
"Shutting up" Breaches.—This is one of the most troublesome and dangerous of operations, and requires constant watchfulness. One of the early records of this class of undertaking is that of Captain John Perry, published in 1721, and entitled *An Account of the Stopping of Daggenham Breach.* The record is not only of engineering interest, but also a human document. The expedients and pitfalls which the author describes are as much in evidence now as in his day, and the same futile methods of attempting to shut up a breach are still in vogue. The description commences with an account of the nature and extent of the breach, which was occasioned by the blowing up of a small drainage sluice or trunk. In consequence, the water found its way in and out of the levels until the gapway became scoured down to the moorlogg and gravel. Parliament was appealed to on account of the impediment the breach occasioned to the navigation of the river, and for fourteen years the breach had gone from bad to worse. The strong current of the efflux from the drowned marshes was felt for miles up and down the river. Many attempts had been made by sinking ships in the breach, pouring in bags of earth, ballast, and chalk, but the only effect of these attempts was to widen and deepen the torrent of water flowing in and out. Captain Perry describes with humour the episode of a large specially-constructed chest, 80 feet long, having been loaded with stones and sunk in the gapway, and, on the following day, this being seen floating down the river. In 1714 an Act was passed ordering the stoppage of the breach at the cost of the State. The Corporation of London advertised for proposals to carry out the work. The sum at which Captain Perry then

assessed the cost of the operation was £24,000, but a rival scheme of £16,000 was submitted. The cheaper scheme having been adopted, failed, before Captain Perry consented to disclose his own method and the Corporation agreed to adopt it. He found the depth of water in the centre of the breach was 40 feet. Owing to the failure of the new attempt the breach had been widened, and eventually the trustees agreed to pay Captain Perry the sum of £30,000, he to forfeit £5000 if the work should prove abortive. He then proceeds to set out in great detail the method by which he proposed to effect his purpose. His design was of a thoroughly practical character. In effect, what he proposed was on the same lines as the practice of to-day, and his calculations are in the main quite sound. Months of discussion then followed, during which matters were getting worse, and eventually the necessary authority was granted him in the worst season of the year—that of the autumn equinoctial tides, when the short days of winter were before him; and he appears also to have had difficulties from drift ice in the river. He found, moreover, much obstruction from the constant attempts of his workmen to scamp the underwater clay work. However, by June in the following year he had succeeded in shutting up the breach, to the great satisfaction of all concerned. In the following month he was prostrated by ague and compelled to return to London. Here, in the month of September, came to him the news that the dam he had constructed had blown up, and the result was the whole operation had to be begun all over again. He remarks quaintly that his assistants must have been asleep, or absent at an alehouse, to allow the mischief to arise. The end of the record is a petition to the House of Commons, in which Captain Perry states that he had spent five anxious years in stopping the Dagenham breach, and had encountered three critical casualties, that the whole of the money voted had been spent, and asking that he might be recouped for his heavy personal expenditure over and above the State grant.

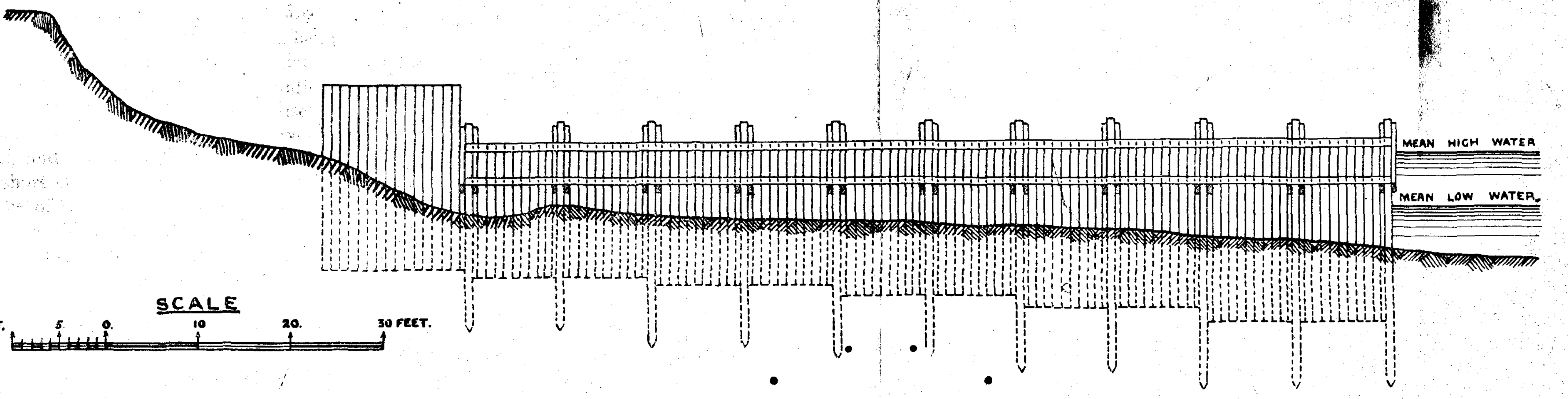
Plate XII represents a breach in a river wall in Essex, closed in 1906. The area of land flooded was 280 acres, and the land had been waterlogged for a period of about eight years,

during which a number of futile attempts had been made to shut out the water. The total length of the breach was nearly 700 feet, and the water impounded was something like 30,000,000 cubic feet. As the tide fell the water poured in a cataract through the central gorge of the breach, which acted as a weir, so that the bed of the river was progressively excavated to a great depth. Owing to the long soakage of the soil over the whole area, it had become so sodden that the extent to which it could be trusted to carry weight was highly problematical. This breach was stopped after one mishap, and the methods by which the result was achieved afford a key to the solution of difficult problems of this nature. The ground in rear of the breach was intersected by a number of arterial ditches, and, owing to the scour of the floods, these converged towards the breach. By driving shuttering either in timber or steel across the line of such ditches, and dropping jute sacks filled with clay in rear of the same, the worst rush of water from the ditches was stanched. After being thus barricaded, the ditches became converted into reservoirs holding up a considerable proportion of the impounded water. The next step was to drive a timber gantry from one side of the breach to the other, the piles being so placed that they subsequently became an integral part of the design of the timber dam ultimately constructed. Sluices were driven through the walls in order to carry off as much of the superficial water as possible as the tide fell. This operation was one requiring much care, as the whole of the walls within which the inundation lay were in so tender a state that further breaches might quite easily have been produced. The main object in the operations was to constrict the orifice of the effluent water as much as consistent with safety, and then, in the course of a single tide, to drop all the guillotine shutters, thus completely closing the exit of the water, care being taken that this should be done as near low water as possible. A large number of bags of clay were also assembled on both sides of the breach, and on the shutters being lowered and made secure, a force of men was engaged in depositing these bags of clay behind the shutters to seal the surface of the bed of the breach, and prevent the blowing up of the timber framing as the head of water increased

Plate XII



ELEVATION OF TIMBER GANTRY FOR SHUTTING UP RIVER BREACH



ELEVATION OF TYPICAL HIGH GROYNE

with the flowing tide. This operation was successfully carried out, and the subsequent procedure resolved itself into providing for the escape of water still impounded through a sluice fixed in the timber staging with that object. Thus, little by little, the volume of water impounded was lowered, and at the same time a constant stream of clay was tipped behind the stage, large quantities of stone having been thrown in front of the toe of the stage to weight it in position and prevent pressure from behind driving it forward. The ground immediately in rear of the breach was so precarious that when the stability of the temporary works was assured an inset wall in rear of these was constructed. By this time the drowned marshes had become to a moderate degree *terra firma*, and the first operation was to cut away the surface of the natural soil for a few feet, so that the inset wall might rest upon a fairly solid platform. The wall was then built up in puddle clay tier by tier. An operation of this character requires the most exact care. The clay has to be dumped in layers of about 12 inches to a uniform level, and then well trodden and punned into the stratum of clay below. In Australia it is a common practice to drive a flock of sheep backwards and forwards over a wall of this kind when under construction. The object to be attained is a complete blending and amalgamation of the layers of clay, so that no veins or fissures remain through which water may percolate and thus cause slips. The inset wall so constructed was laid out to a slope of 2 to 1 on the river face, and 1½ to 1 on the back, and for several lengths, where there was a tendency to slip, short elm piles were driven along the toe. The whole of the face of the inset was subsequently pitched with block chalk 8 inches thick and Kentish ragstone 12 inches thick, carried to within 3 feet of the crest of the wall. The apex of the wall was left 3 feet wide. The unstoned portion of the wall was sown with grass seed. When the inset wall had been completed, and allowed several months to consolidate and season, the timber dam was removed. This required much caution, as small gaps in the timber work would have caused rushes of water, which might have disturbed the equilibrium of the finished work.

The paper of the late Sir John Hawkshaw describing the

bursting of the St. Germains sluice on the Middle Level Drainage near King's Lynn, and the subsequent measures taken to stop the breach, which inundated upwards of 9 square miles, or about 6000 acres, will be found in the *Proceedings of the Institution of Civil Engineers*, Vol. XXII, pp. 497–508. The tidal influx was shut out by the methods detailed above, the impounded water was then drained away and the wall restored.

Following on the lines indicated above, it is safe to say that almost any breach in a sea or river wall may be successfully shut up. There are, however, so many side issues and contingent possibilities that it is an operation requiring experience and skill to avert disaster.

CHAPTER IX

Erosion and Accretion (Works)

Although an inlander, Shakespeare in his sixty-fourth Sonnet has defined with precision the problem of the action of sea forces on a mobile line of foreshore, thus:—

> "I have seen the hungry ocean gain
> Advantage on the kingdom of the shore,
> And the firm soil win of the watery main,
> Increasing store with loss and loss with store".

According to the evidence of the Director of Ordnance Surveys before the Coast Erosion Commission, it would appear that the balance of gain of land over loss of land in the United Kingdom and Ireland, taking the respective dates of the Ordnance surveys detailed by him, was a gain of 41,362 acres. On the basis of the reports of the Board of Agriculture, the total area of land, not including tidal lands, showed a comparative falling off in acreage. In thirty-three years this falling off in the United Kingdom amounted to 182,000 acres. The Director explained the discrepancy as due to the fact that some of the figures in the reports of the Board of Agriculture were estimated. The element of uncertainty already referred to in respect of the delimitation of high-water line on the Ordnance Survey tends to throw some doubt on the accuracy of the official figures in each connection. The notorious fact remains that, whereas large areas of land are disappearing under attacks of the sea, corresponding areas of reclamations or innings are not in evidence. Whichever way the balance of area goes, it is obvious that the land which is being washed into the sea is for the most part good agricultural land, and, in some cases,

valuable town land; while the land from which the sea recedes is in the main a sandy swamp of little intrinsic value.

The foreshore is a plateau of land and water, varying from wide sandy wastes, such as the Shoeburyness sands, to lengths of coast-line which the tide barely leaves. The sea is nibbling on many fronts, but there are comparatively few spots on the British coast where, at the present time, there is marked recession. In the Persian Gulf, blown sand from the desert comes down in such volumes that it is shoaling the Gulf. The vast sand travel along the north-east coast of Brazil is overwhelming, as the sea for several miles from shore is laden with sand in suspension. Movements of sand such as these are almost beyond human control, and any obstruction placed in their way is quickly obliterated.

The most striking record of both accretion and erosion is that of Madras harbour. Along the eastern coast-line of the Indian peninsula, under the impact of the north-east and south-west monsoons respectively, sand had travelled up and down the coast-line almost harmlessly from time immemorial. The Indian Government in 1876 determined to construct an enclosed harbour at Madras. Careful observations were made of the volume of sand travel, and it was estimated that it would take 180 years for the travelling sand to fill a triangular area between the coast-line and a breakwater running out 1200 yards from the shore. No sooner, however, were the works commenced than it became obvious that the above estimate of sand travel was completely unreliable. The wave-borne sand, travelling up from the south, was about sixty times greater in volume than the corresponding amount brought down by the north-east monsoons. The original estimate of sand in motion was 243,000 tons per annum; a second estimate in 1904 was 550,000 tons per annum. The accumulation at the present time shows that about 1,000,000 tons per annum travel along the coast-line. Low-water line between 1876 and 1912 has crept seawards for a distance of 2500 feet (*fig.* 35A). In 1881 a terrific cyclone wrecked the harbour works, then nearly completed, but a somewhat similarly outlined harbour has since been carried out on altered lines. For a distance of more than 3 miles severe

erosion has taken place on the north side of the harbour, due to the arrest of the normal column of travelling sand, and whole towns and villages have thus been swept away. This experience is an extreme instance of the action which goes on in a greater or less degree at every headland, river mouth, or solid projection from a foreshore into the sea.[1]

The ameliorative artificial works by which a coast-line is maintained are in the main sea-walls and groynes. Stability may also be assisted by fostering the growth of foreshore vegetation. When once such vegetation has secured good hold of a coastal area, its effects materially aid the preservation of artificial works. The bane of coastal defence is often the procrastination of landowners and local authorities. In numberless cases action has been deferred until the problem of defence has become tenfold more acute than it would otherwise have been. Moderate expenditure on preventive measures are postponed until costly remedial measures become necessary. It has often happened that a shingle bank has existed and acted as a barrier of defence such that, had steps been taken to avert its dispersal, this state of affairs would have continued for an indefinite time. The comparatively small expenditure necessary for securing this object, however, has not been forthcoming, with the result that such shingle bank has been spread, and its crest lowered, so that it no longer acts as a line of defence in heavy gales. Extreme weather conditions are what do the mischief in such cases. In a single tide, a protective barrier of this class may have its

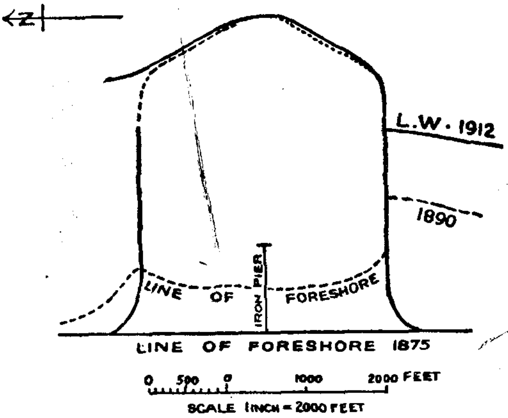


Fig. 35A.—Madras Harbour—Change in Low-water Line

[1] "The Sanding-up of Tidal Harbours" (A. E. Carey), *Proc. Inst. C. E.*, Vol. CLVI, pp. 1–90.

utility destroyed by reason of the crest being driven shorewards, the rollers then passing clean over the bank. Had the problem been taken in time, a light concrete wall, acting as a fence to hold up the barricade of shingle, would probably have saved the situation. By putting such light wall well in rear of the shingle barrier, the process of heaping up goes on, and the sea forces are ultimately powerless to disturb the defence provided by Nature. It is too often forgotten that shingle banks are a definite asset in defence. Once lost they can never be restored or replenished, except by costly measures, involving dumping material from other localities. On a normal coast-line on the south of England, a sea beach will be heaped up by the forces of the waves to a height of about 23 or 24 O.D., that is, 5 or 6 feet above mean spring-tide high water. This action often goes on to 27 O.D. or higher.

As regards the strength of sea-walls, obviously if a good shingle bank exists in its front a lighter wall suffices. It is desirable in most cases to carry the level of the top of such sea-wall to a height of 8 or 10 feet above mean spring-tide high-water level.

The contours of sea-walls have furnished much debate. It is extremely doubtful if the large additional expenditure necessitated by many abnormal designs is justified. A sea-wall and its allied natural defences of the foreshore are, after all, intended to stop the run of the sea in the same fashion that a bullet is stopped by a target. It is a question of weight versus momentum, and mere finesse of design under these circumstances is not worth paying for. Many of the sections adopted are based on sound theoretical lines, but it is probable that an ordinary straight-fronted wall, having a batter of about 1 in 8, would have given better value for the expenditure involved. Curvilinear and stepped walls necessitate undue capital outlay in construction. By a somewhat thickened section stability could be equally well obtained at less cost.

Destruction of a sea-wall has frequently been brought about by the digging action due to the cascade of water recoiling from the face of such wall, and striking its pervious foundation at the toe. In this case a trench is excavated along the front

edge of the wall by the rush of water, and the wall falls outwards. In the majority of instances this effect is due to the fact that proper measures have not been taken to conserve the accumulations in front of the wall, or, as an alternative, to dump shingle or stone along its frontage, which method would have created a buffer between the stroke of the waves and the wall.

In a great number of cases, the first idea of those responsible for works of this class is to build a structure as massive, and therefore almost as expensive as a breakwater. From the ratepayers' point of view this may be magnificent, but it is not business. The art of design is to effect the desired end by making Nature do your work for you as far as that is practicable. There are exposed positions where, almost inevitably, a sea-wall has to bear the brunt of the full momentum of heavy seas. Under such conditions, no doubt a curved or stepped wall is more effective than a wall with a nearly vertical face, but it is in the main doubtful if the ratio of its efficiency in this respect could not be achieved by less costly methods. One expedient of this character is the formation of an apron at the toe of such wall. Reinforced concrete will probably be found the most efficient material in its construction. Great care has to be taken to carry the apron sufficiently seawards, and to build its front edge sufficiently deep to counteract the effect of the scour induced by recoil from the wall, which is apt to set up a guttering action, thus tearing out and undermining the front edge of the apron and causing its collapse. An apron built with this object should be constituent with the wall, and the reinforcement between the wall and the apron fairly massive, to counteract the tendency to cracking by unequal settlement at the junction of the apron and the wall. The apron also requires to be built with expansion joints, so that minor settlement may not cause dislocation and thus disintegration.

In nine cases out of ten the policy of pushing the edge of a parade to the extreme limit seawards is the cause of much of the useless expenditure entailed on the fronts of sea towns. It is a form of greed which recoils upon itself, as the amenities of a seaside resort are greatly enhanced by leaving a strip of open ground between its houses and the actual foreshore. By

this means the growth of the natural protecting medium of defence can generally be so fostered as to obviate the necessity of massive works fronting the beach.

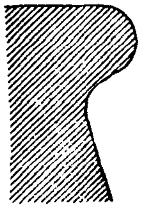


Fig. 36.—Bull-nose Coping

The question of a bull-nose coping to a parade wall is also one which has given rise to much discussion (fig. 36). This design is intended to throw back the spray tangentially from the crest of a wall, and thus prevent its sweeping over the parade. It is obvious that in so doing the blow of the sea is largely resisted by the coping, which action must set up severe stresses in the wall. By dumping, if a sufficiency of shingle or sand does not exist, and a well-devised system of groyning to hold the accumulation, the momentum of the sea can be, to a large extent, absorbed before the waves actually strike the wall, and thus the whole *raison d'être* of the bull-nose coping disappears.

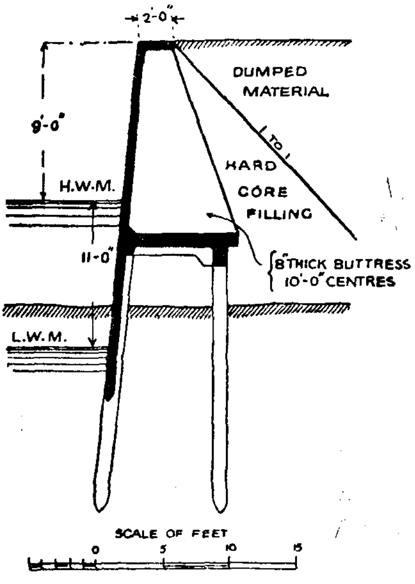


Fig. 37.—Carnarvon Sea-wall (Reinforced Concrete)

Recent investigations on wave impact[1] have brought to light the fact that, where fissures or open joints exist on a sea-wall, the dynamic pressure of a wave may multiply the force of the blow fifteen times. A dynamometer pressure of 2 tons per square foot would, on this basis, be equal to a pressure of 465 lb. per square inch, a force which would severely stress an ordinary masonry joint.

The introduction of reinforced concrete is revolutionizing marine construction. Fig. 37 represents the section of a sea-wall recently erected on the North

[1] "Wave Impact on Engineering Structures" (Professor Gibson), *Proc. Inst. C. E.*, Vol. CLXXXVII, pp. 274–91.

Wales coast. The cost of this wall was £6. 10s. per lineal foot, and not only had the wall to withstand severe sea attack, but, owing to the fact that the filling behind it could not be deposited at the time of its construction, to be left unsupported. It has fulfilled its function with complete success. Fig. 38 is a section of the sea-wall built at Hove. Fig. 39 represents that of the west spur of Newhaven breakwater. In these instances a solid concrete structure has cheaply fulfilled the prime function of a

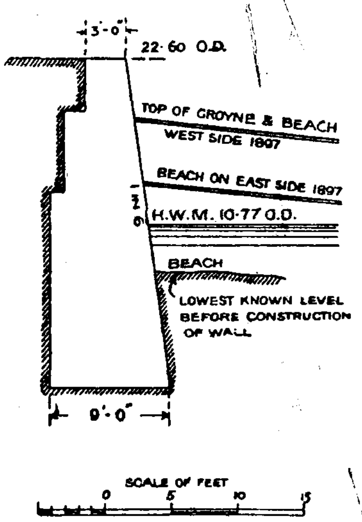


Fig. 38.—Hove Sea-wall (Mass Concrete)

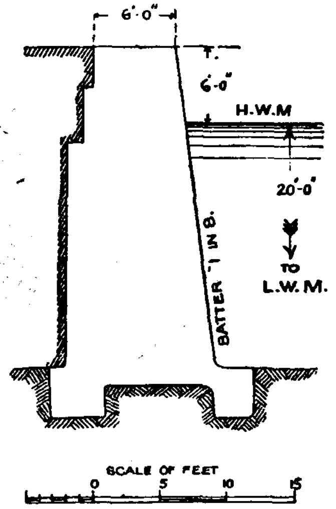


Fig. 39.—Newhaven Sea-wall (Mass Concrete)

sea-wall under severe conditions of exposure. Wherever practicable, it is eminently desirable to build a sea-wall in mass concrete rather than in blocks, as a monolithic structure is less liable to dislocation than a structure intersected by joints.

In many of the textbooks the question of sea defence is treated as a matter of mere cash debit and credit. On the one hand, the cost of constructing foreshore works of defence is defined, and the assumed value of the land to be protected is set in an opposite column, and schemes are either approved or condemned on the standard of direct profit and loss. It is probable that in the near future these problems will be dealt with in a different spirit. So far as the cost of foreshore works

is concerned, the figures of a year or two back no longer hold good. On the other hand, it is likely that issues deeper than the mere money value of the land concerned will be the dominant factor in future proposals of this class.

It has been calculated that if three-fourths of the cost of groyning those portions of the coast-line of English counties most affected by erosion were charged on the respective counties, they would represent the following rates:—

> Sussex, 1*d.* in the £;
> Norfolk and Suffolk, 1¼*d.* in the £.

The assumption in this case is that the landowners immediately affected would provide one-fourth of the total cost, the counties pay the balance. At a rough approximation, about 500 miles of the coast-line of England and Wales are in varying degrees subject to erosion.

The action of depletion is due in the main to oblique littoral drift. Where a coast-line is sandy, the wind-waves throw the sand into suspension, and the currents drive it along the shore. On a shingle coast-line wind-waves are the prime motor in its movement. Rollers bring in shingle and sometimes large masses of rock from deep water. It frequently happens that, after a severe gale in the Channel, boulders weighing several hundredweight will be found strewn along the strand. These are mostly weed-covered. The growth of weed evidences the fact that the action of the waves has reached sea depths normally tranquil. In exposed portions of the coast-line of Scotland, boulders upwards of 2 tons in weight are similarly thrown up after storms, and their occurrence on these spots is so much a matter of course that they go by the name of "travellers". Their buoyancy being increased by the crop of seaweed they carry, they are pushed along the sea bed under the impulsion of the deep-water rollers. As an instance of deep-sea wave action may be cited the fact that concrete blocks at Peterhead harbour, weighing 47 tons, were forced out of position at a depth of 40 feet below low water.

Under normal weather conditions, shingle or sand on a foreshore hugs the coast-line, moving to windward or leeward

under the alternation of the wind-waves. On the English Channel, the prevailing wind exposure being from the west and south-west, eastward littoral drift is the normal condition. In a few instances, however, due to recoil under the lee of salient points, wave action and the currents are locally reversed. Thus at Newhaven, before the breakwater to the west of the harbour was built, the uniform movement of the beach was from west to east, but for a distance of some three miles to the east of Newhaven the shore forces now swing round in the opposite direction, driving the beach, and more especially the sand, from east to west.

In the North Sea the severest wind conditions are those from the north-east, gales from the south-west being off-shore. The coastal phenomena of the English Channel are there repeated, as from the quarter of greatest exposure.

The building of groynes has been, broadly speaking, a matter of trial and error. The expedient is coeval with foreshore defence. Groynes laid out to all sorts of angles, and of every variation of design, occur along the English coast-line; in fact, some lengths of shore-line are almost museums of devices of this type. The established standard practice of twenty or thirty years ago was to lay out groynes at right angles to the shore-line. As, however, the direction of a groyne and the coincident stroke of wind-waves are collateral, it is obvious that no uniform rule adequately applies to a coast-line which may be infinitely varied in trend. Theoretically, if the stroke of the maximum wind-waves on a groyne impinges at an angle of 45 degrees, this would be the ideal condition. Groynage is, however, governed by so many local considerations that no broad universal rule can be established. The factor which proves good design in groynage is the equality of accumulation to windward and leeward of the structure. Wherever a foreshore consists of a series of steps, shingle being banked up to a great height on one side of its groynes, alternating with bare patches of foreshore, it is safe to say that the trend of the groynes is badly designed. Where a line of groynes is deflected to form an acute re-entrant angle with the windward stroke of the waves, a condition of danger is created, as the run of the sea is thus

impounded in the angle between the groyne and the barrier of defence behind it. The sea being gorged, its force is concentrated, and the danger of the destruction of the groynes by direct impact increased, as well as the scouring effect. Under these conditions the force of recoil is intensified, with the result that beach is dragged down along the line of the groyne and a deep gutter created, tending to undermine its foundations. Probably, in the majority of instances, a groyne placed nearly at right angles to the maximum force of the wind-waves gives the best results. Its direction may be modified a few degrees to windward or leeward of this line, as observation of the action on a particular stretch of coast-line indicates.

The tendency of the designers of groynes protecting one particular stretch of coast is to trap all littoral drift. This is in effect to starve the coast-line to leeward. The ideal condition is that of circulation in compartments, the column of drift oscillating under the varying conditions of wind and weather, and leaving, as nearly as practicable, a uniform incline on which the sea forces may spend themselves harmlessly.

At the outlet of a harbour or river the construction of spur groynes is one of the most efficient devices. It achieves two results:—

(*a*) The arrest of the travel of the circulating medium, thus preventing the formation of bars or spits, which distort the contour of the outfall of the harbour or river, cause an impediment to its flow, and set up conditions detrimental to navigation.

(*b*) A well-formed spur groyne forms an embayment, and if a series of these is constructed, retardation of travel is brought about, so that on the windward side of a harbour or river an artificial ness is created, sheltering the foreshore. The action of coastwise retardation of shingle or sand may by this expedient be prolonged and a dangerous coast-line effectively defended. The critical portion of a spur groyne is on the outer edge at its junction with the main groyne. It there receives the full stroke of on-shore seas, and the tendency to

scour is greatest. At this point, therefore, special precautions in design have to be taken.

With regard to the determination of the height of groynes, their purpose and situation have to be carefully studied. The classic instance of defence of a low-lying sea frontage is that of Romney Marsh. From points of vantage in the town of Rye, the vast expanse of this marsh, dotted with cattle and sheep, may be realized. The low-lying area is about 60,000 acres, much of it 10 or 11 feet below high water. The severest seas strike from the south-east, as Dungeness affords shelter from the south-west. The marsh includes some of the fattest pasturage in England, and measures for defending it go back to Roman days. About a hundred years ago, Sir John Rennie advised on a system of groyning carried out with brushwood held in position by hop poles. Thereafter the bank appears to have been neglected and left very much to chance conditions.

At the commencement of the Victorian era, a new *régime* of defence was inaugurated, the sea slopes being paved with stone pitching laid on concrete, the lower slopes at a gradient of 1 in 9, the upper at 1 in 7. As far as practicable, the stonework was flushed with cement. This system was followed by pronounced erosion, heavy storms in 1859 and 1869 tearing out great areas of the stone pitching, an effect induced by the action of underwater scour, set up by the recoil from the paved foreshore, or that described by Captain Calver as "scavenging".

During the next twenty years, a sum of nearly £70,000 was expended on patching the foreshore, but on the appointment of the late Mr. Case as expenditor its condition had grown serious, as in the year of his appointment areas of over 8 acres of stone pitching were scoured out. Heavy groyning was recommended, but Mr. Case eventually carried through a complete system of low groynage. The timber scantlings he adopted, though of an unusually flimsy description, proved effective. He embedded the groyne uprights in concrete pits sunk in the foreshore. He thus built 420 groynes, and sometimes completed a groyne in the day. The result of the system he adopted has been the preservation of this dangerous coast-line, and the accumulation

of several million yards of drift, mostly sand, at relatively small cost. The protection of Romney Marsh affords a striking instance of success achieved by economical expedients, and of the abandonment of costly heroic measures which would have eventually led to disaster.

The system of low groynes, although in the majority of instances desirable, is not universally so. The art of building up a foreshore is to adjust the height of the groyne system to its accumulating volume of littoral drift. After depletion it is often prudent to remove planking from groynes in order to cause less obstruction to the run of the sea. Conversely, when rapid accumulation takes place, additional planking should be added to capture such travelling medium of defence.[1]

On foreshores where extreme artificial conditions exist, high groynes are sometimes essential, and if such groynes were lowered erosion would at once commence. The sea front of Brighton is a case in point. The cliffs to the east of Brighton having by groynage been starved of their natural protection, have been severely eroded, the coast-line being set back in a deep indent, which involved a detour of the high road to Newhaven. The bank of shingle thus accumulated to the westward of Kemp Town is an artificial barrier, which would be quickly lost and the front of the town threatened if the groynes were lowered. By prolonging a system of groynes seawards, and thus creating a plateau of foreshore at a flat gradient, the most efficient defence is secured. Plate XIII (p. 140) shows a groyne constructed on a point of maximum erosion on the East Coast. The building of this groyne involved much difficulty, as during its construction the width of foreshore was only 26 feet at low tide, and seas of extreme violence were rapidly undermining and causing landslides in the glacial-deposit cliff in rear. By a system of low adjustable groynes the safety of the threatened section of sea frontage has been completely secured, the coast-line for about a mile being thus rendered safe at an expenditure of about £2000. At the present time the groyne shown in Plate XIII is high and dry at low tide, and a flatly shelving foreshore, with wide stretches of velvet sand,

[1] *Protection of Seashores from Erosion* (A. E. Carey). Greening & Co.

exists in advance of it, recent accumulation being several hundred feet in width.

In building some of the old groynes, more especially on the South Coast, an armoury of oak timbering was used, the practice being to drive a secondary row of piles and connect the main structure with these by sticks of unsquared oak timber. These ponderous structures are, however, now few and far between. They were excessively costly, and proved no more effective than groynes built with ordinary piling and planking.

The substitution in groynes of reinforced concrete piles in lieu of timber has been recommended, and in one or two instances adopted. It is, however, open to the objection that piles of this character are costly, that the difficulty of varying the height of such groyne is increased, and that the attrition of the shingle where much sea action takes place tends to scour the skin of concrete away and bare the steel reinforcement, which, in its turn, corrodes.

In all probability, on the English coast creosoted pitch-pine piling will be found in the great majority of instances the cheapest expedient practicable. The depth to which these piles have to be driven, and the scantlings necessary, must be gauged by the local conditions prevailing at the particular spot. The patent system of the late Mr. Case, arising out of that adopted at Romney, whereby piles were embedded in concrete foundations, has on exposed foreshores proved unsatisfactory, as entire structures so built have in several instances been rooted out bodily by the sea.

Taking the normal type of timber groyne, piles can either be driven in pairs, the planking being secured between, or alternately on either side of the planking, and on a coast-line of small exposure a single row of piles will sometimes suffice. Probably the most efficient structure results from fairly deep piles and longitudinal planking bolted alternately to right and left of such piling. The head of groynes should be carried to a fore-and-aft line of defence—either a sea-wall, a cliff-line, or an embankment. The practice which has sometimes been adopted, of leaving a gap between the shoreward end of the piling and the fore-and-aft defence is disastrous, as the swirl of the sea

running up the face of the groyne roots out and scours away the material at the head of the groyne and sets up destruction along the shore-line.

The length to which groynes should be carried seawards depends largely on local conditions. Normally, on an exposed foreshore to be defended by a system of groyning it is desirable to carry at any rate some of the groynes from 50 to 70 feet beyond low water. It is this portion of the groyne which is most effective in building up the beach and preventing the dispersal of the material. The result, moreover, is the flattening of the foreshore slope, which is a great end to be attained.

One of the most difficult problems in connection with coast defence is the protection of the coast-line of British Guiana. The low-lying portion of the colony consists in the main of deltaic alluvium, and its soil, agriculturally fertile, is unsuited to resist the inroads of the sea. The wind *régime* on this coast follows a regular sequence. During three months of the year attacks of the Nortes recur. When these hurricanes sweep down their effect is incredibly severe. The North-east Trade winds blow steadily for the rest of the year, but in the autumn months the sudden stroke of the Nortes is a recognized phenomenon. Under the impulsion of these winds a furious rolling sea strikes the coast-line. According to the Report (dated 1910) of the Colonial Commissioners appointed to enquire into the subject, it would appear that the average annual expenditure on sea and river defences for the previous ten years had been not less than £12,000. In the previous forty years the average rate of coast erosion had in some localities been 32 feet per annum, and many vital façades of the colony were thus threatened. A lack of continuity of defensive measures to cope with the trouble seems to have rendered the efforts of the colony somewhat ineffective. The problem of the Guiana coast-line would appear to resolve itself into three elements:—

1. Measures to render the crest of the coast-line immune from the actual transit of the seas.

2. Measures for safeguarding the visible foreshore of the coast-line. In this respect systematic plantation, supplemented by some defensive work, would appear to be necessary.

3. Below the visible foreshore the most promising expedient would appear to be that of fascines, but fascines of special design, in view of the extreme conditions.

The most recent systematic construction of groynes on a large scale is that carried out on the coast of Jutland between Ferring and Agger.[1] The physical characteristics of the land in rear of the coast-line along this frontage of about twenty miles greatly resemble the conformation of the coast-line of Suffolk and Norfolk. In both cases the superficial deposits are those left on the melting of the ice after the Glacial epochs. Extensive areas of marshy country and lakes with connecting streams have in each instance thus been dammed back. The principal impounded waters on the Danish side are those of the Limfjord. This is a wide expanse of mere, and the Thyborón Canal has been cut out as a navigable approach to it. The Limfjord is a valuable fishing area, and had the attenuated coast-line between it and the North Sea been breached, much rich agricultural land would have been converted into swamp and the fisheries destroyed. The sea bed consists of fine sand with a little shingle, and here and there, at a depth varying from 16 to 32 feet, of sandy alluvial clay. The total expenditure incurred by the Danish Government on the defence of this strip of coast up to July, 1913, was £666,000. Of this sum about £55,000 was spent on what are termed "preliminary works". The Danish authorities, not having had previous experience in groyne construction, deposited blocks of concrete, in which the sand-mortar varied in proportion with the aggregate, and in many cases these blocks subsequently disintegrated. Up to 1894 the practice had been to mix the concrete 1:3:6 and even 1:4:8, but after this date the aggregates were mixed 1:2:4, and subsequently 1:2½:5½. The final proportion for the mortar appears to have been a mixture of 37½ lb. of cement to the cubic foot of sand. The sand was white quartz sand, nearly all passing a sieve of 774 meshes per square inch, and nearly all retained on 5800 meshes per square inch. A longitudinal dike or embankment in concrete was constructed, and the

[1] "Experiments upon Mortar, and Diatomaceous Earth as Puzzolana, in Sea-water; with special reference to Groynes in Denmark" (A. Poulsen), *Proc. Inst. C. E.*, Vol. CC, pp. 409–20.

groynes were placed 1230 feet apart. The longitudinal embankment cost about £5 per lineal metre of coast. The groynes were 620 feet long; at the shore end 14¾ feet above mean water-level, and with a mean fall of 1 in 60. The part nearest the shore had a slope of 1 in 20, the seaward end of 1 in 80. The size of the concrete blocks used in the groynes was about 62 cubic feet, each weighing about 4 tons. In the early stages of the work the granite boulders strewn on the sea bed of the Cattegat were used. For some portions of the front the dike was carried considerably in rear of the coast-line, and the intervening space became filled with blown sand.

One matter of interest in connection with these works was the disintegration of the blocks. Unless complete water-tightness is secured in forming concrete structures, the percolation of the sea water is liable to cause disastrous disintegration, its effect being that the free lime under these circumstances is attacked by the sulphate of magnesia in the sea water and a chemical combination results, which causes the rupture of the concrete. In order to circumvent such mischief, which has been fully investigated on its chemical side in England, the Danish engineers experimented with the addition of various siliceous earths occurring in the peat districts. The difficulty to be overcome is in its ultimate issue a physical one, as if the concrete used is free of intersticial porosity, the penetration of the magnesium salts is prevented. The diatomaceous earth thus used as a diluent and pore-filler passes under a number of different names in various localities. Its essential ingredient is silicic acid in an active condition. The material which the Danes call Mo-ler is found in the Thyborón district, containing about 70 per cent of silicic acid. To each cubic metre (say 3080 lb.) of Portland cement, 1320 lb. of the local earth were added, and the two ingredients ground together. The effect of the combination appears to have been satisfactory in preserving the resultant concrete from disintegration.

One broad issue in respect of policy is to be noted. Denmark, a relatively poor country, in order to safeguard agricultural and fishing industries, has constructed from national funds seventy groynes, with intervening dikes, at a large

capital outlay. The area behind the corresponding English coast-line, relatively of greater value, is left without systematic defence against the inroads of the sea.

The principal types of groynes on the English coast, other than those already described, may be summarized as follows:—

Type No. 1 consists of piles about 12 inches square, driven from 8 to 10 feet apart, planked on one side, and with a single waling on the other, and held down by land ties secured by rows of short piles to right and left. The planking has to be carried a few feet below the lowest beach level, and the piles are sometimes stiffened by having short strips of railway metal bolted to them.

In *Type No. 2* the vertical timbers of the groyne proper are carried by transverse sole pieces attached to two rows of piling, the uprights being in pairs and the planking placed between them, with rakers as in the last instance. This is an undesirable type of construction.

Type No. 3 is similar to Type No. 1, but instead of timber piles old railway metals in pairs, with planking between, are used, and the ties are also of iron. This type is not to be commended, as it is difficult of adjustment, the iron corrodes, and after a heavy gale is apt to become twisted out of shape.

Another system is a modification of the Case groyne, already described, its essence being to embed the uprights of the piles in concrete pockets. The lower half of the uprights of the groynes in St. Margaret's Bay are so embedded, the upper half of the piling being driven in the ordinary way. Sometimes raking timbers are only fixed on one side of groynes of this character. Some years ago the patent Dowson groyne was exploited, and a few such groynes were erected. The principle of this is to substitute for planking a steel mesh between the piles, the theory being that the shingle would be caught on the mesh and the weight of the water allowed to pass through the groyne. These groynes, though highly ingenious in design, have not commended themselves in practice.

A distinct form of groyne is the box groyne, which consists of two rows of piling, both being planked, and the intervening space filled either with beach or rock. This type is doubly

expensive, and very liable to disintegration. It approximates to the practice in Holland, where the groynes (*golfbrekers*), are usually about 500 feet long, spaced about 200 yards apart, and run at right angles to the shore. Golfbrekers are elaborate structures, in fact breakwaters in miniature. They are sometimes laid in the form of a mound reaching at the sea end a few feet above low-water level, and they rest upon fascines. The summit of the mound is basalt-pitched, with two pairs of rows of piling, one on either side; brick rubbish is placed over the fascines, and the basalt pitching laid on edge on the brick-work, the outer slopes being protected by dumping loose masses of stone pitching, either basalt or limestone. In some cases the crest of such groyne or breakwater is protected with concrete slabs instead of basalt pitching, the other portions of the section being as already described.

On the Brighton front groynes of the most formidable character have been erected. These are in effect massive stone piers faced with flint and with a hearting of mass concrete. The sides of these piers are mostly built at a batter of about 1 in 4, and sometimes they are laid out as promenades. At Dover a somewhat similar pier, 10 feet in width at the top, running almost level for about 100 feet, and then dipping at inclinations of 1 in 5, 1 in 6½, and 1 in 8 down to low-water line, the total length of the pier being 289 feet, was built in 1860. At Hastings a concrete pier was built at the spot which was, at the date of its construction, the extreme east end of the foreshore of the Corporation. The result of this obstruction has been the arrest and impoundage of an enormous mass of shingle. Immediately to the east of the pier there is a sheer drop of about 25 feet, and the foreshore of sandstone rock is severely eroded. The east cliffs, purchased by the town for the purposes of a recreation ground, are now vigorously attacked by the sea, as they have no protection at their foot. Almost every winter great landslips take place there.

In the instances of these three towns, which are fairly typical, is demonstrated the vicious circle of original bad planning which has brought about so much destruction of the coast-line. The towns have gradually grown up to an arbitrary sea con-

tour, and there is nothing for it but to maintain that artificial frontage.

Those who are responsible for thus keeping intact dangerous salients are compelled to resort to sea-walls and groyning of so massive a character that they are unassailable. The defences of the town in effect constitute a blockade, which starves the coast-line to leeward and destroys the regular sweep of the shore, a factor setting up the familiar phenomenon of irregular inroads of the sea.

The distance apart of groynes is a matter which must be dealt with on purely empiric lines. If it were attempted to evolve a formula or general law on the subject such formula would have to be in terms of the angle of inclination of the foreshore to the horizon and the local rise of tide. These are the main factors in determining the point. A rule commonly stated is that of placing the groynes a distance apart equal to their length, but such spacing is purely arbitrary, and is not based upon any physical reason. The average inclination of the foreshore on the English East Coast is about 1 in 15, the inclination on the English Channel averaging about 1 in 11. Where the foreshore runs down into sandy flats the gradients of these are up to 1 in 100.

The profile of the foreshore of the Dutch coast is variant, but along its sandy flats the ruling gradient may be probably taken as about 1 in 30 to 1 in 40, and on the sea marge as flat as 1 in 100.

One matter of serious moment in connection with the conservation of a coast-line is that of land drainage, more especially where high ground or cliffs abut on the seashore. The instances of the North Parade at Scarborough and of the sea front at Frinton may be quoted. In the former case, with the object of diverting land drainage, an expenditure of £26,000 was incurred, and in the case of Frinton an intercepting drain was laid for a length of 3860 feet at a cost of £1390. It is probable that by systematic and scientific planting a threatened land slope contiguous to a foreshore may to a large extent be partially unwatered, and the expense of heavy drainage works thus lessened.

With regard to the life of foreshore structures, this varies to a great extent with the exposure and the nature of the materials of which they are built. The Local Government Board has no standing rule on the subject in respect of the periods for which they give authority for loans, but the following are their usual terms, which are rarely departed from, and they furnish a fair index, being based upon long experience:—

Esplanades	30 to 20 years.
Concrete groynes	20 years.
Reinforced concrete groynes	15 years.
Wooden groynes	10 years.
Pitching	5 years.
Sea-walls	20 years.

A rough approximation of the average cost of normal wooden groynes in the past may be taken at 25*s.* per lineal foot, but the variations in this figure were extreme, and ancient history has little value in respect of current work.

Below low-water mark the travel of sand goes on almost unimpeded. This travel is one of the most troublesome problems. In a few hours the results of many laborious months of dredging may be completely obliterated. In older engineering practice the problem of sanding up has been perennial. Harbour engineers and those responsible for navigation have been completely baffled, and many a promising harbour, on which a large expenditure has been incurred, rendered almost useless for the special traffic to be catered for. The underwater movement of sand and the ease with which it adjusts itself to altered conditions may be illustrated by a parable.

In the folk-lore of present-day Yorkshire, and going back thence to remote Scandinavian legend, is a belief in a domestic attendant sprite, Hob by name. Shakespeare calls him Puck. The exploits of this demon are sometimes malicious, sometimes beneficent. After a period of vexatious ill-luck, obviously the handiwork of Hob, the story runs that once on a time a troubled farmer determined to find safety in flight. With his household gods on a cart, a neighbour meets him. "Ah sees thou's flittin'," says the neighbour. "Ay," Hob pipes out of a churn, "ay, we'se flittin'."

In the ports on both sides of the Channel, as the sand travel has perplexed harbour authorities their traditional policy has been to push the entrance piers into deeper water as a means of eluding sand travel. Inevitably, as the piers are extended seawards, so the sand has crept out after them.

The sum of the palliative measures may be stated as—

(1) To conserve and concentrate the tidal scour of the ebb tide;
(2) To train the sea outfall;
(3) To dredge.

CHAPTER X

Plant Winning of Tidal Lands—Salt Marshes

The Salt Marsh is tidal land *par excellence.* Its basis consists of silt and mud, that is, of the most finely-divided erosion products. These materials carried in suspension into estuaries or other sheltered positions, such as the lee side of spits, &c., tend to be precipitated at slack water. In these positions the mud is normally colonized by vegetation to form salt marsh. When in fullness of time a vigorous mixed vegetation has arisen, occupying a level overrun by the spring tides only, the marshes are termed "saltings".

Salt marshes, more than any other type of maritime land, show continuous change, both in the details of their topography and in their vegetation covering. In the case of shingle it is the exceptional storm or super-tide that determines important topographic re-arrangements, whilst for effective movements of sand on a dune system winds of considerable velocity are necessary. With mud, on the other hand, the normal daily flow and ebb of the tide are entirely adequate to transport and redistribute the particles. The most gentle of currents will lift and carry particles of clay, e.g. one flowing at 0.17 mile per hour (0.25 foot per second). The process operates at every tide; mud is being moved from one place and deposited in another. The aggregate result is topographic change. Creeks meander like rivers; ground is eroded away; silt is deposited on the saltings and their level rises. The change in level affects the physical character of the soil, whilst, with a rising level, the period of tidal submergence is shortened. Such changes unfit

the ground for the pioneer plants, and make it suitable for the establishment of other species, which operation finds expression in vegetation change.

The more important salt-marsh areas in England include the estuary of the Severn, the waters about the Isle of Wight, the mouth of the Thames, the north coast of Norfolk between the shingle fringe and the mainland, the Wash, the Humber, Morecambe Bay, and the Solway.

The original source of the materials is by no means easy to trace in all cases, for its determination depends either on following the particles in transit, or it has to be inferred from a detailed examination of the silt. Thus, there has been and indeed still exists a difference of opinion as to the origin of the "warp" in the Humber. According to one view it is derived from the rivers which converge to form this estuary; according to another it is brought up from the coast, where it is derived from the erosion of the soft cliffs which stretch northward from Spurn Point. Final decisions on such matters cannot be reached by guesswork, but must depend on long-continued systematic observations analogous to the records of the meteorologists.

Broadly speaking, there can be little doubt that the materials in question are derived largely from the products of land erosion brought down to the sea by rivers, and that this source is supplemented by a greater or lesser amount of silt produced locally on the shore. The ratio between these two components will vary in different cases according to the hardness of the rocks involved and to other circumstances. In process of time the materials of all grades, shingle, sand, and mud, will be separated and classified by the sea. Whilst the heavier elements will in large part be thrown up as shingle beaches or sand-banks, and only under very exceptional circumstances pass beyond the zone of wave mobility, the mud which is long held in suspension will be deposited as to a part in sheltered estuaries, whilst the rest will drift out to sea, where it will fall in deep water and be lost to the coastal zone.

Data illustrating the muddiness of tidal waters in the British Isles are not very abundant. The following figures refer to the

shore waters of the Bristol Channel, where it has been ascertained that on the average every gallon of water in a flowing tide holds in suspension 40 grains. As the area involved in these observations was roughly 225 square miles, and reckoning the depth of water at 6 feet, there would be some 700,000 tons of mud on the move. Put in another way, for every square foot of ground there are 4 oz. of mud in suspension in the 6 cubic feet of water which stand above it.

The circulation of mud is thus considerable, though, of course, in the British Isles there is nothing comparable to the huge amounts of suspended matter discharged from the mouths of great continental rivers. The Mississippi, for example, is stated to convey into the Gulf of Mexico every year 363,000,000 tons of detritus, enough to cover an area of 240 square miles to a depth of 1 foot.[1]

But in any case it is hardly to be expected that the coast-line of Britain should provide the conditions of salt-marsh formation on the grandest scale. These belong to large continents with vast interior reserves of erosible mountain chains and highlands, not to small islands. Speaking quite generally, and without reference to the nature of the rocks, the erosible materials yielded by any land area will be proportionate to its area. That is to say, the volumes of detritus eventually brought down to the shore, per unit length of coast-line, will be functions of the radii of the land areas involved.

Topography of a Salt Marsh.—Commonly the ground of an estuary or other inlet occupied by salt marsh falls into two principal areas, i.e. the higher level terrace or salt marsh proper, covered only at the spring tides; and the lower flats in part bare, which are covered by every tide (Plate XIV). These regions are distinguished by us as "Saltings" and "Slob lands", by the Dutch as *Schorre* and *Slikke*. Here they will be referred to as High and Low Marsh, respectively.

It is a character of high marsh to be carpeted with a continuous turf of vegetation, the basis of which is the common Salt-marsh Grass (*Glyceria maritima*), and mingled in this turf is a considerable variety of plants, of which the most frequent

[1] W. H. Wheeler, *Tidal Rivers*, 1893, p. 60.

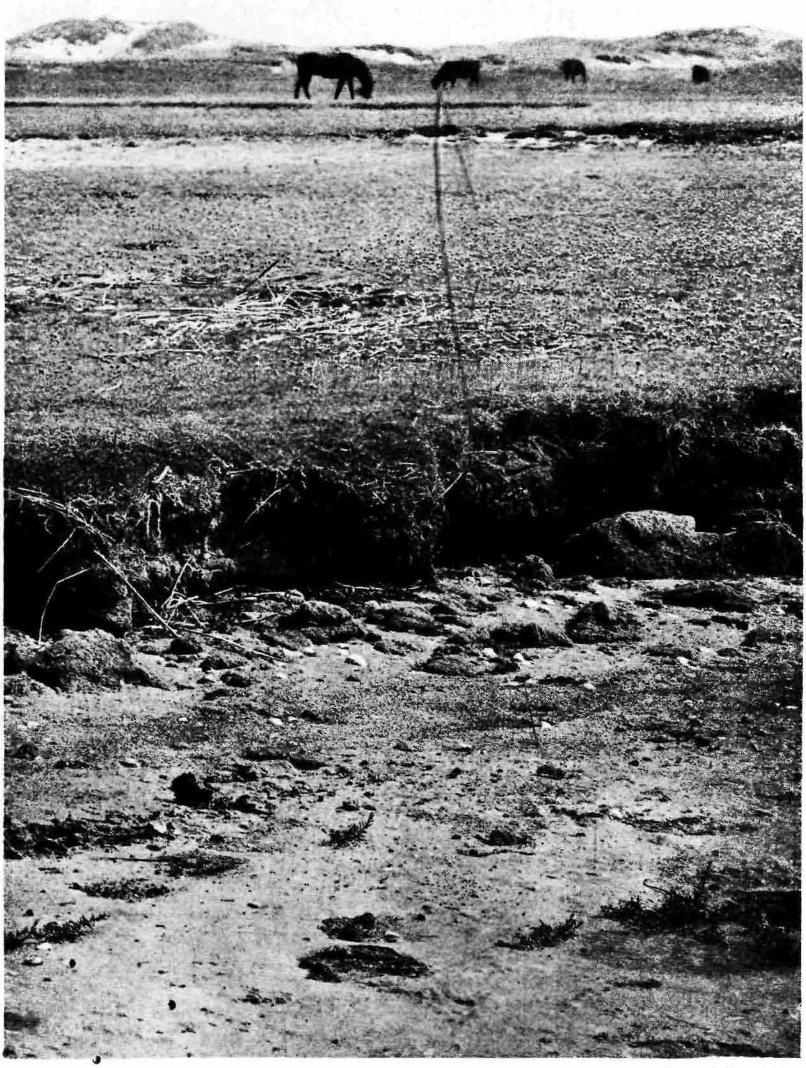


Photo. J. Massart

BOUNDARY BETWEEN HIGH AND LOW SALT MARSH

High Marsh with turf of *Glyceria maritima* and much *Armeria maritima*; Low Marsh bare with scattered *Suæda maritima* (Right-bank, Estuary of Yser, Belgium)

are the Sea Plantain (*Plantago maritima*), Sea Lavender (*Statice Limonium*), Sea Pink (*Armeria maritima*), Sea Purslane (*Obione portulacoides*), Sea Aster (*Aster Tripolium*), and Sea Spurrey (*Spergularia media*).

High marsh is traversed by numerous creeks or channels, by means of which the tide gains access to and drains off the marsh. There are usually one or more principal creeks and numerous subsidiary ones into which these branch. The tributaries get shallower and shallower till they die out on the marsh surface. On many salt marshes they end in low, wide depressions termed "pans". These pans are apt to be bare of vegetation and usually retain sea water after the tide has run off. The beds of the creeks are bare of vegetation except where the sides have caved and fallen in. The system of creeks is the circulatory system of the marsh, and provides not only for the movement of water but also of silt. Much silt is transported by the creeks, and when they overflow the silt is carried on to the surface of the marsh, where it is fixed by the vegetation. High marsh on the side towards the main channel of the estuary generally ends abruptly in a low cliff 2–3 feet high. This cliff, like the sides of the smaller creeks, is liable to erosion.

Where high marsh adjoins the mainland the ground rises slightly, and is usually characterized by the presence of dense tufts of the Sea Rush (*Juncus maritimus*), with which the low-growing Sea Milkwort (*Glaux maritima*) is often associated. This peripheral zone, termed the Juncus zone, is covered by the higher spring tides only. Its chief interest, in relation to the economic exploitation of salt marshes, depends on the fact that the rush being a most obstinate and deep-rooted plant, it has to be specially grubbed up in marsh reclamation, otherwise it may persist for half a century or more, to the great detriment of the grazing value of the area it occupies.

Low marsh is covered by every tide; its lower stretches consist of bare mud, whilst the higher parts are colonized by pioneer flowering plants, of which the most characteristic are several annual species of Marsh Samphire (*Salicornia annua*, *S. ramosissima*), at once recognized by their cylindrical, leafless stems, recalling in habit a small, smooth cactus (fig. 40). These

plants occur in more or less open formation, that is to say, the bare mud is visible between them. Some species (e.g. *S. ramosissima*) are liable to be coloured red, especially in autumn, by a pigment which masks the natural green coloration. Where the plants grow at all thickly they form vivid crimson patches, a most telling feature in the sunlit landscape. Another annual plant that occurs on the same ground is *Suæda maritima* (fig. 41). Both these plants drop their seed on the mud in the late autumn and die, though their dead stalks generally resist weathering till the following spring, when the next crop of seedlings appears.

Fig. 40.—*Salicornia annua*, half nat. size

Fig. 41.—*Suæda maritima*, half nat. size

Another very characteristic plant of the low marsh is the Grass-wrack (*Zostera marina* and *Z. nana*), with narrow, ribbon-like leaves spread out on the mud. Zostera reaches a lower level than either Salicornia or *Suæda maritima*, and most commonly occupies mud too soft to walk upon without sinking.

Besides these flowering plants the low marsh bears a quantity of Algæ, especially Enteromorpha, Rhizoclonium, and Vau-

cheria. The two latter are filamentous, whilst Enteromorpha, at first ribbon-like, may, when full-grown, become a hollow cylinder. As we shall see, Algæ are by no means excluded from the high marsh, but undoubtedly they are most abundantly produced at a lower level. They play an important part both mechanically as mud-binders, and, later, as manurial agents when they are washed up with the drift.

Between the two types of marsh no hard-and-fast line exists, for low marsh is continually in process of transformation into high by accretion of mud and the entry of other species of plants. At the same time the converse process is in operation, and high marsh gives place to low as a result of undercutting. This process is aggravated when from any cause, such as the disappearance of a protecting point of sand or shingle, some part of the marsh becomes exposed to increased scour by the sea. Under these altered conditions areas of high marsh may be rapidly degraded. In rare cases, as when shingle is washed to and fro on the actual surface, the tufty covering may be abraded to such an extent that the marsh suffers erosion superficially as well as by undercutting. However, increased local erosion is usually counterbalanced by increased accretion somewhere else. A marsh is always able to assimilate much greater quantities of silt than are normally forthcoming. This power to accrete depends on the mud-holding faculty of the vegetation, and is dealt with more fully in a separate section at page 198. The question is sometimes asked whether in process of time the level of a salt marsh may not be raised so high by silting that the sea is automatically excluded; in other words, whether a marsh may not naturally reclaim itself? So far as we know salt marshes are never reclaimed unless the sea is banked off either artificially by the construction of sea-walls, or naturally by the throwing up of shingle beaches or sand dunes. Provided the level of the land is not rising, the sea would never appear to abdicate the prerogative of undoing its own handiwork.

Peculiarities of Salt-marsh Vegetation.—The plants which inhabit salt marshes belong to two great classes of plants, the Algæ and the Spermophytes or higher plants.

The Algæ.—The normal vegetation of the sea consists of the seaweeds, or Algæ, of which there are some 770 species on the coasts of Britain.[1] These plants fall into four groups according to their colour—blue-green, green, brown, and red, and they occur in the greatest profusion where a rocky shore provides a firm substratum for attachment. The majority of Algæ, in contradistinction to land plants, have no need of an absorbing root to penetrate the ground in the case of attached forms; a disk or attachment sucker suffices to hold them to the rock, whilst the operation of absorption of water and dissolved salts is effected by the whole surface. The capacity of marine Algæ to exist in sea water, which contains in solution nearly 3 per cent of common salt, is rendered possible by the high internal pressure of their sap. If, for example, freshwater Algæ are transferred to sea water, they undergo collapse and disorganization, because the relatively high concentration of the sea water brings about the outflow of the water of the cell sap of the Algæ. The higher concentrations normal to seaweeds, however, render them immune from this danger.

Salt marshes and other aggregations of coastal detritus are physically unsuited to the requirements of most seaweeds. The great majority of such as are met with occur attached to the shells of mussels, which afford a firm anchorage. A few occur on pebbles in sheltered positions, but in the case of Algæ attaining any considerable dimensions the pebbles are liable to be drifted up to high-water mark, which is a position not usually suitable for most Algæ.

A certain number of Algæ, however, have fitted themselves for existence on muddy shores, and these, though specifically few, occupy a great expanse of ground. Biologically, it is convenient to distinguish two groups: (1) those that merely cling to the surface of the mud; (2) those that penetrate into the mud, becoming, as it were, part of its fabric.

Of the surface dwellers the most conspicuous are Enteromorpha, Rhizoclonium, and Ulva.

Enteromorpha forms tiny ribbons which may expand into hollow tubes. It occurs on low marsh reaching down to the

[1] We are indebted to Mr. A. D. Cotton of Kew for this estimate.

low-water mark of the larger channels. The young plants are attached at one end to the soil particles, but as soon as they attain visible dimensions they are drifted to higher levels by the tide. Vast quantities of Enteromorpha are thus continually produced at lower levels, and make their way eventually to the drift line, generally rolled by the tide into ropes. Here they disintegrate into humus, and contribute to the maintenance of other plants in the way already described (cf. p. 111).

Rhizoclonium is a filamentous Alga found especially on the wetter parts of high marsh. In winter and spring it grows with the greatest luxuriance, and is of great importance in covering and anchoring the seed of the spermophytes of the salt marsh. The annual plants in particular derive an evident advantage from their algal nurse.

Ulva latissima deserves mention here on account of the nuisance caused by its putrefaction on certain foreshores. This Alga has a thin, membranous, expanded thallus of variable size, often reaching 1 foot in length and 4 to 6 inches in width. To stones or rock it is fixed by its attachment disk, but on the sheltered, muddy foreshores of estuaries, where extensive mussel beds are present, Ulva may occur in vast quantities attached to the byssoid threads excreted by the mussels. These threads form a very favourable mechanism for the purpose, and in brackish estuarial waters contaminated by sewage, such as Belfast Lough, where mussels are widely distributed, the Alga flourishes with the greatest luxuriance between half-tide level and low-water mark. The ammonia from the sewage promotes the rapid growth of the Ulva, especially during the summer months, whilst the extensive mussel beds provide the necessary anchorage.

When in autumn the Alga becomes detached from its moorings it is heaped up in banks on the shore; it undergoes putrefaction, and by the evolution of sulphuretted hydrogen creates at times an intolerable nuisance.[1] Experiments on a fairly large scale show that the nuisance can best be mitigated by the

[1] See in particular *Royal Commission on Sewage Disposal*, 7th Report, Vol. II, Appendices, pt. i, 1911. For the botanical report on Ulva in relation to this nuisance, by Mr. A. D. Cotton, see *ibid.*, pp. 121–42.

removal of the mussels, or by their destruction *in situ* by the application of copper sulphate.

The most important of the bedded-in Algæ are *Fucus vesiculosus*, form *limicola*, *Vaucheria Thuretii*, and *Microcoleus chthonoplastes*, each of which deserves a word of description.

Fucus vesiculosus limicola is really a form of the common Bladder-wrack seaweed (*F. vesiculosus*), which occurs on every rocky shore. It appears to originate from the parent type in a purely vegetative manner, and assumes its remarkable growth habit in response to the special marsh conditions. *Fucus limicola* occurs on the upper 3 feet of the low marsh, the

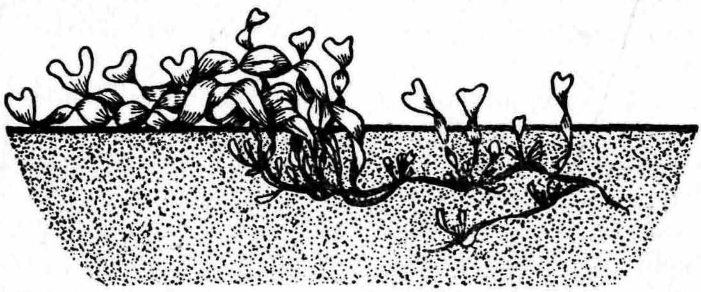


Fig. 42.—*Fucus vesiculosus*, form *limicola*, bedded in mud and proliferating to the surface. (After Dr. Sarah Baker.)

upper limit of its range being at or slightly above the high-water mark of the neap tides. It occurs in part on bare mud (as in Plate XV, lower photo.), and also mingled with the pioneer colonists of the high marsh. It is distinguished by the narrow segments of its frond, by its sterility, and especially by the liability of the segments to be spirally coiled. Lying prone on the surface it becomes embedded in the mud, through which, however, it always pushes up numerous branches (fig. 42). Within the limits of its zone the plant carries on in this vegetative fashion, the parts that become embedded undergoing decomposition and enriching the soil. As level rises and other plants come in it assumes the secondary rôle of undergrowth; eventually it is crowded out by taller plants. In the history of marsh development *Fucus limicola* plays an important part in catching and holding silt, and also in the enrichment of the soil.

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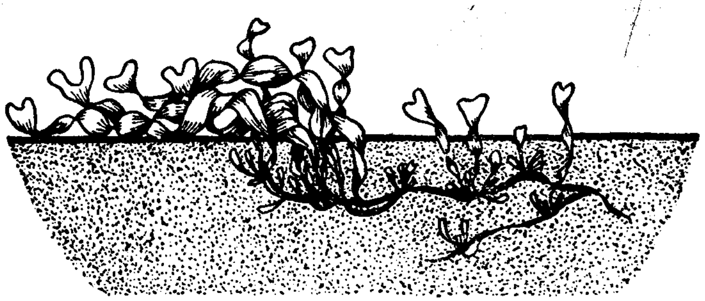

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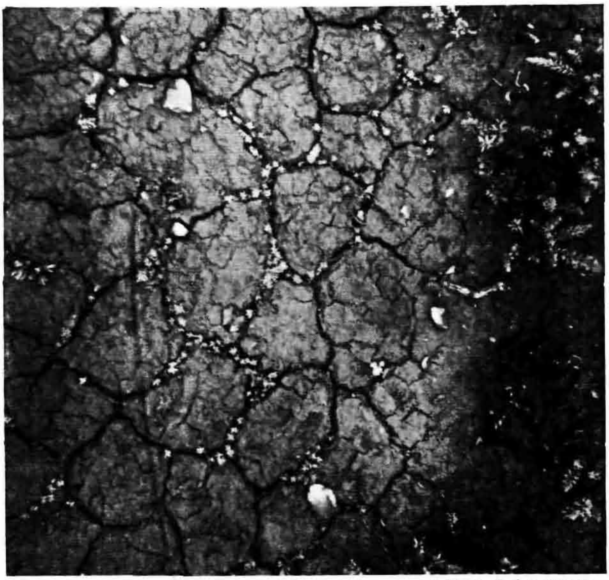


Photo. E. J. Salisbury

Sun-cracked Mud with the Alga *Microcoleus chthonoplastes*; Seedlings of *Suæda maritima* arising in the cracks

Photo. supplied by Dr. S. M. Baker

Mud Slope covered with *Fucus limicola*; Aster and Salicornia are beginning to settle (Mersea Island, Essex)

ALGÆ AS PIONEERS ON MUD

Vaucheria Thuretii is a green filamentous Alga and *Microcoleus chthonoplastes* a blue-green. Otherwise they play closely similar rôles in mud-fixing, the Vaucheria on low marsh, Microcoleus over a wider range—from ordinary low-water mark to ordinary high-tide level. The embedded portions form a close meshwork of mucilaginous consistency, which holds the mud so tenaciously that practically none of it is washed out even when the surface layer is rubbed between the finger and thumb under a tap of water. The ends of the algal tubules project above the surface as a short-piled velvet, and trap any silt that the tide drifts along. These two Algæ between them occupy extensive surfaces otherwise bare, and within the limits of their zones are most efficient catchers and holders of mud.

Microcoleus sometimes does its work so well that the surface cake is impenetrable to germinating seedlings. However, in dry weather the cake is apt to crack in hexagonal fissures, and seeds, finding their way into these fissures, germinate and establish under the most favourable conditions. (Plate XV, upper photo., seedlings of *Suæda maritima* are arising in this fashion in the cracks of Microcoleus-covered ground.)

The relation of almost all plants to the silting process is fundamentally the same as these two Algæ. The portions of the plants which project above the surface tend to slow down the rate of flow of the layers of water that pass over them, with the result that the silt in course of transport is dropped and becomes entangled. The plant continues its growth through the new surface, and the process is resumed. The principle is just the same when Marram grass catches wind-borne sand, or *Suæda fruticosa* shingle from a passing wave. It is the eternal tendency of plants to stabilize the ground they occupy and to detain such fresh particles as enter their net.

The Higher Plants.—These are technically called "Halophytes", to distinguish them from the ordinary terrestrial and freshwater flowering plants.[1] Numerically, the halophytes form not more than 1½ per cent of the total flora. Higher plants

[1] The term "halophytes" is used to designate plants that grow rooted in soils impregnated with salts. Strictly, marine Algæ are excluded, though it is evident the two groups have in common their relation to a saline environment.

number about 2000 species in the British flora, and of these not more than 30 occur between tide limits, some 20 only being really common. Though the species that occur on salt marshes are thus in point of numbers markedly inferior to those of the sand dune and shingle beach, they carpet the ground more densely.

It is hardly necessary to explain that these plants are able to thrive in saline habitats in virtue of the high sap concentrations which they oppose to the sea water, concentrations which are found to vary according to the degree of salinity of the ground. Sea water contains approximately 3 per cent of common salt, but during dry periods between the spring tides the soil water may undergo concentration, reaching a strength of even 6 per cent NaCl. On the other hand, if heavy rains follow the spring-tide cycle much of the salt will be washed out (especially where much sand is present), and the concentration may fall to 1 per cent NaCl. It was proved by T. G. Hill that halophytes are able to accommodate their sap concentrations to the rise and fall of salinity in the environment, and that these adjustments are even rapidly effected. Probably all plants show these adjustments within limits; what characterizes the halophytes being the high upward extension of which they are capable. A great feature of most halophytes is their succulence, a character they tend to lose when grown in ordinary soil. For the most part halophytes of the salt marsh are smooth and succulent, but this is not invariable, as the Sea Purslane (*Obione portulacoides*) is covered with scurfy, and the Sea Wormwood (*Artemisia maritima*) with woolly hairs.

In Appendix IV, p. 267, a fairly full list of British salt-marsh halophytes is given, with the addition of the restricted number of families to which they belong. The most important of these families is that of the Chenopodiaceæ, a family always represented wherever plants of the salt marsh or other saline soils occur. Next in importance come the Grasses, Crucifers, the Plantaginaceæ, and the Plumbaginaceæ. A few of these plants demand special mention from their importance in various ways. The occurrence of these plants, as with the Algæ, is zonal, that is to say, each has a definite and restricted vertical distribution

in its locality. Probably no other plants are so defined in their positions as are the halophytes.

Salicornia annua is the staple plant of the earlier phases of salt-marsh development and especially of low marsh (fig. 40, p. 168). In young high marsh *S. annua* often occurs densely crowded in almost pure formation. Later on it is largely superseded by other plants, except on the barer places. It is renewed each year from seed, and dies in the autumn.

S. dolichostachya, closely related to *S. annua*, has long, tapering flower spikes. This species is preferred for pickling as "Samphire" on the east coast, as at Blakeney (Plate XXV, 1, p. 232).

Fig. 43.—*Obione portulacoides*; a young trailing specimen, ¼ nat. size

Salicornia ramosissima plays the same part as *S. annua* in other localities.

There are several other annual species of Salicornia in Britain, but of less importance than the foregoing.

Salicornia radicans is a perennial species rooting from the procumbent shoots. In sandy salt marshes it is important as a hummock builder (cf. p. 189), and is apt to persist for many years.

Obione portulacoides follows *Salicornia annua* when the latter has raised the level of the marsh appreciably by silting. It forms a low, grey, straggling bush about 1 foot high, and characteristically occupies the banks of the creeks. In sandy marshes it often raises the height of the banks by filtering off the sand as the tide overflows them (Plate XVI, 1). Occa-

sionally Obione overruns a whole marsh, and in virtue of its size and density obliterates the other plants (Plate XVI, 2). It is a perennial, and its prostrated branches root from the nodes the second spring. The branches being brittle become detached easily, and are apt to lodge and root elsewhere. Seedlings are also formed, but appear in quantity only in occasional years. The reason for its rather striking preference for the banks of creeks has not been ascertained. This plant contributes much material to the tidal drift; its ash is rich in potash. A trailing specimen is represented in fig. 43.

Grasses.—The most widely distributed of all salt-marsh grasses is *Glyceria maritima.* On Salicornia marshes it follows the pioneer, gradually establishing a turf. It forms the general matrix of most high marsh, and is of value for grazing in the later phases. The closeness of its texture and its capacity to grow through make it a most efficient accretor of silt (Plate XIV, p. 166).

On sandy marshes it often occurs as a pioneer forming hummocks. Here, and on other surfaces which it covers, it arrests the silt and continues its peripheral growth.

Festuca ovina v. *rubra* is another grass found on the higher levels of the salting, and especially on banks and beaches liable to occasional tidal inundation. It has great value in holding the ground; also for pasture.

Triticum pungens likewise occurs on the higher levels, and is perfectly halophytic.

Spartina Townsendii is a grass of particular importance, and claims the attention of all who are interested in the utilization of salt marshes. Being of recent apparition, and its potentialities not yet fully gauged, we deal with it here at some little length. The existence of this plant first attracted general attention when Lord Montagu of Beaulieu reported on its occurrence in 1907 to the Royal Commission on Coast Erosion.[1] Having property on the Solent between the Beaulieu River and Lymington, Lord Montagu had witnessed the early colonization and gradual spread of *Spartina Townsendii* (known locally as "Rice Grass") over the tidal flats till it had come to occupy

[1] *Royal Commission on Coast Erosion and the Reclamation of Tidal Lands*, Minutes of Evidence, Vol. I, 11290–300, 11341-62.

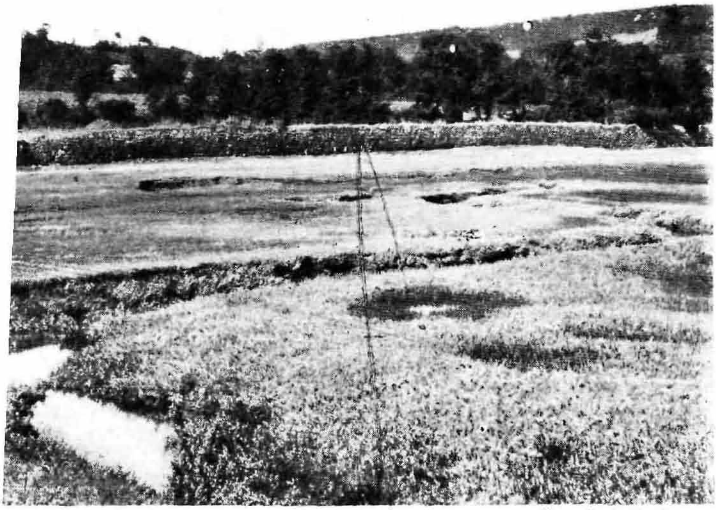


Photo. Dr. S. Hastings

nall Creek bordered by Obione, which has raised banks by trapping the silt (Bouche d'Erquy)

Photo. Mrs. Cowles

ed Salting invaded by Obione, which has overrun the flat, all but the strip intersected the seated figure. The bushes on the bank are *Suæda fruticosa* (Blakeney Point)

OBIONE PORTULACOIDES

thousands of acres, and was consolidating and building up the ground. The appearance of this plant was a comparatively recent phenomenon, and its spread was still in active progress. The matter was at once referred by the Commission to the authorities of the Royal Gardens, Kew, for more information, and Dr. Otto Stapf took up the enquiry from the botanical and topographical points of view.[1] The description which follows is based largely on Dr. Stapf's account.

Of the small group of species which constitutes the genus Spartina, most are natives of the Atlantic coast of America. One species, *Spartina stricta*, is indigenous to Europe, occurring in salt marshes from the Wash to the Mediterranean. A second species, *Spartina alterniflora*, of American origin, has been established in Southampton Water for a hundred years, no doubt accidentally introduced. The first record of *Spartina Townsendii*, the species which claims our attention, was at Hythe, on Southampton Water, in 1870. Twenty years later it was spreading rapidly, and it now occupies enormous areas in the waters around Southampton and the Isle of Wight. In 1899 a few plants were detected in Poole Harbour, and these are still spreading everywhere over its intricate system of creeks and mud flats. To the east it has spread in the same way to Chichester Harbour, whilst latterly it has found its way to the estuaries of the Rivers Saire and Vire, which discharge on the eastern side of the Cherbourg Peninsula.

Spartina Townsendii "is a vigorous, stout, stiff grass, standing usually about 2 to 2½ feet high, but occasionally much dwarfed, or drawn out, and then attaining a height of from 3 to 4 feet. It grows mainly in the soft ground of the mud flats, which are so common on the Hampshire coast and the adjoining portions of the coasts of Dorset and Sussex, and in the tidal reaches of their rivers. It anchors itself in the mud by long, vertically-descending roots, whilst another set of roots,

[1] See Dr. Stapf's *Evidence before the Royal Commission on Coast Erosion*, Vol. II, 16284–381. Also Stapf in *Gardener's Chronicle*, Jan. 18, 1908, p. 33, and *Proc. Bournemouth Nat. Sci. Soc.*, Vol. V, p. 76, 1913. Also R. V. Sherring, *ibid.*, Vol. IV, p. 49; Vol. V, p. 48; and Vol. VII, p. 42. Mr. Sherring's notes form a most valuable record of the gradual spread of the plant in Poole Harbour. It is to be hoped that later on it may be possible for them to be thrown together into a continuous narrative.

short but abundantly divided and interlaced, spreads all round from the base of the stems and the nodes of stolons close to the surface of the mud (fig. 44). It grows in tufts (Plate XVII. See frontispiece), which often assume great dimensions and a remarkably circular shape. Such patches may measure anything between 3 and 15 feet in diameter, and even more. The grass owes this peculiar growth to the production of numerous underground branches or stolons, which grow out from the buried stem bases radially, and measure from a few inches to several feet. Inequality in the density of the mud, admixture of sand, pebbles, or larger stones, and other conditions may favour development in one or the other direction, when the circular shape of the clumps gives way to irregular shapes, or it may be that two or more clumps meet in the course of expansion and fuse, and finally many clumps may unite and form regular meadows with a dense matted growth.

"The leaf-blades are rigid, long, and long-pointed, standing off at angles of 60 to 70 degrees, and bright green or slightly glaucous. Like all the Spartinas, it has the spikelets closely arranged in stiff, one-sided spikes, which spring from a common axis, and are erect, so that they are almost or quite applied to each other. There are usually four to seven of them, but starved specimens may have only two, and luxuriant specimens as many as eleven. . . . The grass begins to flower in the latter part of July, and the flowering is most profuse in August and September. Some individuals, however, lag much behind, and may be found in bloom as late as the end of December. As each spikelet contains only one flower, it also has only one grain, which remains tightly enclosed in its husks. . . . The spikelets become easily detached when ripe, drop into the water, and leave the bare spindles standing up stiff like spears until they break down along with the stems, which gradually decay during the winter and spring. The ripening of the grain takes place mostly in October."[1]

As with many other seaside plants, the output of seed is rather uncertain, and appears to be influenced to a marked degree by the weather during the flowering season. Doubtless

[1] O. Stapf, *Proc. Bournemouth Nat. Sci. Soc.*, Vol. V, pp. 77–8.

Fig. 44.—*Spartina Townsendii*, complete plant with stolons, long anchoring roots, and interlacing surface roots. Autunm condition. One-fifth nat. size

the occurrence of bumper years accounts for the sudden invasion of new areas, for which the plant is famous, whilst in the following years the numerous seedlings thus established will expand into clumps, which eventually join to form extensive meadows. Dr. Stapf reports that filamentous green Algæ are instrumental in anchoring the seeds to the mud, so that they remain and germinate—a process we have noted in the case of several other halophytes, e.g. Rhizoclonium, p. 171.

Plate XVII (see frontispiece) shows an early and characteristic stage of colonization in Holes Bay, Poole Harbour,[1] whilst the upper picture (Plate XVIII) was taken in the adjacent Lytchett Bay. In addition to *Spartina Townsendii* (marked Sp.), this photograph shows belts of *Scirpus maritimus* (Sc.), and *Phragmites communis* (P.) growing in the foreground. The latter plant is the familiar reed of freshwater rivers and lakes; on the salt marsh, however, it behaves as a halophyte, being perfectly tolerant of saline submersion. The lower picture on the same plate shows a tongue of meadowed Spartina advancing into an arm of Poole Harbour.

The outstanding feature which makes *Spartina Townsendii* pre-eminent among the halophytes is the extraordinary vigour with which it spreads into new ground. The flats which it invades form the upper tidal zone, extending downwards some 4 to 6 feet from the high-water mark. This ground in the Southampton area consists mainly of soft mud flats, into which a man walking sinks knee-deep. It was formerly covered mainly by Zostera. Where the Spartina has united to form continuous meadow the ground gradually becomes firmer, and at places in Poole Harbour cattle walk down on to the marshes to browse on the plant. At present Spartina sweeps all before it in this zone, and is rapidly raising the level of the ground. Of course this cannot go on indefinitely. Judging by analogous cases, a time must come when the level has been raised to a height less favourable to Spartina than the present mud flats, and it will then be gradually ousted by other plants better adapted to the new conditions. At present, however, Spartina

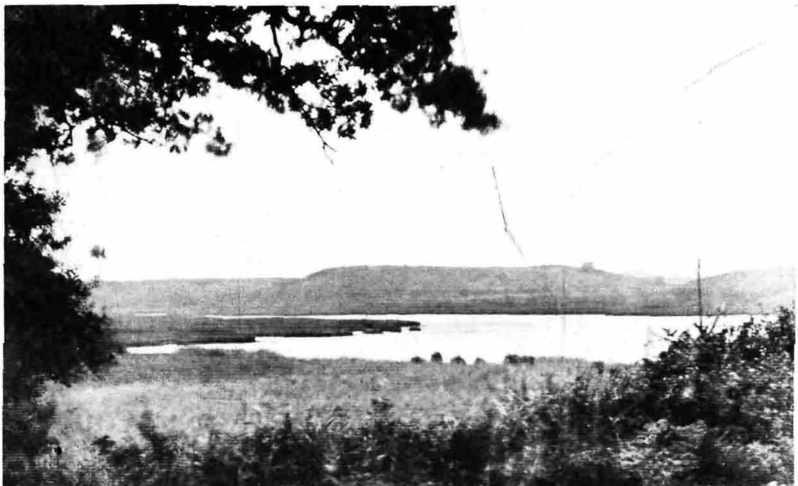
[1] Taken by Mr. R. V. Sherring, as also Plate XVIII, lower picture, to whom we are indebted for the use of the photographs.

Sp.

Sc.

P.

Spartina Townsendii (Sp.), *Scirpus maritimus* (Sc.), and *Phragmites communis* (P.) growing together in Lytchett Bay, Poole Harbour



A dense tongue of Spartina advancing into an arm of Poole Harbour

SPARTINA TOWNSENDII

is in the phase of youth, and it is too early to say with certainty by what plant or plants its place will be taken.

Experimental cultivations have already been made in the Medway, in Somerset, at Wells in Norfolk, on the Firth of Forth; and in New Zealand. As the plant has established satisfactorily in these various stations, it is evident that it tolerates a wide range of conditions. Of its capacities as a natural reclaimer much has still to be learnt; in fact, Spartina has as yet hardly begun to be exploited. In due time, no doubt, some agency will be established for its export to distant countries, a desideratum in view of its capriciousness in seed production. It is necessary that experts should be ready on the spot to take advantage of another bumper harvest like that of 1911.

The effect of *Spartina Townsendii* upon navigation only time can show. Not that there is any fear of its occupying and blocking navigable channels, for Spartina operates in a higher zone. But the presence of a plant which invades the mud flats, and promises to raise their level to a marked extent, must encroach by just so much on the space formerly accessible to tidal waters. In other words, after Spartina has done its work, less water will flow up the channels than was formerly the case, and less will flow down again. Should this mean a deficiency of scour on the ebb, there is a likelihood of the channels silting up, as has happened in many other cases. As the natural reclamation of many square miles of marsh land would ill compensate for impaired facilities of navigation, it behoves the appropriate authorities to use great vigilance. Carefully planned observations at the present time, or in the near future, should be capable of detecting what may be the trend in this matter, and if trouble is brewing, steps could be taken to restrict or eradicate the Spartina, e.g. by gas poisoning or other chemical agencies. We are referring, of course, to Southampton Water and Poole Harbour.

Curious as it may appear, the colonization of the mud flats of Poole Harbour is reported to be accompanied at first by an appreciable deepening of the creeks and channels. This effect is probably due to the fact that the travelling silt of the creeks, which formerly moved up and down with the flow and ebb of the tide, is now fixed on the mud flats by the Spartina—the

creeks being to this extent depleted of mud and deepened. It would be a serious error, however, to suppose that this effect will continue. As the Spartina flats rise by silting, the storage space for tidal water will undergo a corresponding diminution, and the volume of water available to scour out the channels at the ebb will grow less. If we assume that through the agency of Spartina the mud flats rise only 1 foot, and that the area of Poole Harbour involved is 10 square miles, this amount of accretion will diminish the capacity of the harbour to accommodate tidal water to the extent of about ten million cubic yards—in other words, there will be this deficiency in the volume of the ebb for the purpose of scouring the channels.

The Origin of Spartina Townsendii.—Nothing is certainly known on this point except that its appearance was first recorded near Southampton in 1870. At that time the two other species, *S. stricta* and *S. alterniflora*, existed together on the area, and as *S. Townsendii* is in many respects intermediate in its structural characters, it has been pretty generally assumed to be a cross or hybrid between the two.[1] This view finds strong corroboration in the fact that at the only other spot in the world where these two species are known to overlap in their distribution, viz. the mouth of the Bidassoa River, south of Bayonne, in the Bay of Biscay, a form of Spartina closely similar to *S. Townsendii* was found in 1895. This form, which was named *S. Neyrautii*, is regarded by experts as a naturally-produced hybrid of *S. stricta* and *S. alterniflora*. All that can be said is that the coincidence is remarkable, and that the inference that both *S. Townsendii* and *S. Neyrautii* are hybrid forms, derived from the same pair of species, is almost irresistible. The matter can only be settled by breeding experiments in competent hands.

To recapitulate so far as *Spartina Townsendii* is concerned. This plant appeared for the first time in Southampton Water nearly fifty years ago. Since that date, owing to its remarkable constitutional vigour, and suited by the ground, it has spread in a miraculous way on the mud flats of the Southampton system and in adjacent estuaries to east and west so as to threaten

[1] O. Stapf, *Proc. Bournemouth Nat. Sci. Soc.*, Vol. V, p. 81.

entirely to cover them with dense continuous meadows. At the same time, by its accreting action the level of these flats is being raised and their consistence consolidated. The area occupied is already to be measured by thousands of acres, and the only limit to its future spread is the extent of suitable ground available. In 1907 attention was directed to the phenomenon by Lord Montagu's evidence before the Royal Commission on Coast Erosion, and since that date the plant has been kept under observation.

At the same time, serious attempts on a proper scale have yet to be made to determine the economic value of this remarkable plant—whether it can be employed profitably, and under what conditions, for forage, litter, hay-making, or the manufacture of paper, in addition to the provision of means for its distribution as a reclaiming agent. Moreover, its marked increase in navigable waters raises the question whether its spread in some of the localities already occupied may not develop into a serious menace. These are all matters that should long since have received close attention from an authority in a position to take action. Were our coast-line properly supervised there should be no fear of such a matter being overlooked.

Occasional isolated cases of the employment of Spartina in accretion and coast defence are on record. The Californian town of Reclamation is stated to be laid out on ground built up from the sea by *Spartina glabra*, whilst on the Demerara River (British Guiana) another species, *Spartina brasiliensis*, has been employed in an ingenious way by Mr. John Junor, the manager of certain estates in the district.

The method consists in planting the foreshore with Spartina, and when it has become established and collected soil, Mangroves (Rhizophora) are planted amongst it, with the result that a forest springs up and no further attention is required.

The details are as follows:[1]—

"Mr. Junor informs me that he plants the tufts of the grass (*Spartina brasiliensis*) in rows, the rows being six feet apart, and the plants in the rows separated by a distance of two feet. The depth at which the tufts are planted

[1] The account quoted was written by Mr. A. W. Bartlett in the *Journal of the Board of Agriculture of British Guiana*, Vol. I, No. 3, January, 1908. It is reprinted in Vol. IX of the same journal, July, 1916, pp. 180–2; the reprint alone has been seen by us. We are indebted to Mr. Alleyne Leechman for calling our attention to the matter.

is about one foot below the surface. The grass spreads quickly, so that in a short time the plants meet to form a patch, the numerous stems of which serve to fix the mud and prevent it from being washed away by the sea. Even should the mud cover up the plants after they have been planted they are able to make their way through it in time."

"When the grass is firmly established Mr. Junor's plan is to plant the seedlings of the mangrove in amongst it. There follows a great development of roots both from the trunk and the branches of the mangrove, which, after the manner of flying buttresses, firmly support the tree in the soft mud and enable it to withstand the strongest breezes and the heaviest seas. These aerial roots being more or less curved allow a certain amount of 'give' or play, which is often of advantage in enabling a structure to withstand pressure without collapsing. So the mangrove tree is in many ways particularly adapted for growing along muddy sea coasts which are exposed to winds and waves. The young plants grow rapidly, and in a few years will themselves produce a crop of seedlings. The club-shaped seedlings are obtainable in abundance along the coast, and should be gathered for planting when they are nearly ready to fall.[1] All the planting that is required is merely to *insert the lower pointed end of the seedling in the mud.* When the mangrove trees have grown to a fair size they form a close shade, and so far as my observation goes they kill out the 'wild rice' (Spartina), which appears to require full exposure of the sun's rays for at least a part of the daytime for its successful growth. But by the time that the mangrove trees have reached a sufficiently large size to do this, they will themselves have taken over the functions of the 'wild rice' in preventing coast erosion, and hence the latter is no longer required."

Other Perennial Halophytes.—This short review of the plants of the salt marsh may conclude with some mention of a number of common perennials, most or all of which are to be met with on nearly every marsh. They include the following species:—

Sea Pink or Thrift (*Armeria maritima*) (fig. 45), Sea Lavender (*Statice Limonium*), Sea Plantain (*Plantago maritima*), Sea Arrow Grass (*Triglochin maritimum*), Sea Aster (*Aster Tripolium*), Sea Spurrey (*Spergularia media*). In their typical occurrence all these plants first appear as seedlings relatively early in salt-marsh development, some even when the marsh is still in the Salicornia phase. As the level of the surface rises by accretion, the individuals already established persist, whilst new ones continue to establish, at any rate for a time. In this way the pioneer phase, in which annual Salicornias and perhaps

[1] One of the peculiarities of Rhizophora is its vivipary, i.e. its seeds germinate whilst still attached to the parent plant.

Suæda maritima play a chief part, gives place to a secondary phase or "succession" in which the ground is mainly held by perennials, of which the above-named, along with the ubiquitous grass *Glyceria maritima*, are examples.

The whole of these forms are rosette-plants, that is to say, the foliage is produced in tufts at the surface of the ground. Branches rising above the surface only occur in connection with flowering, and the inflorescence axes so produced (whether leafy,

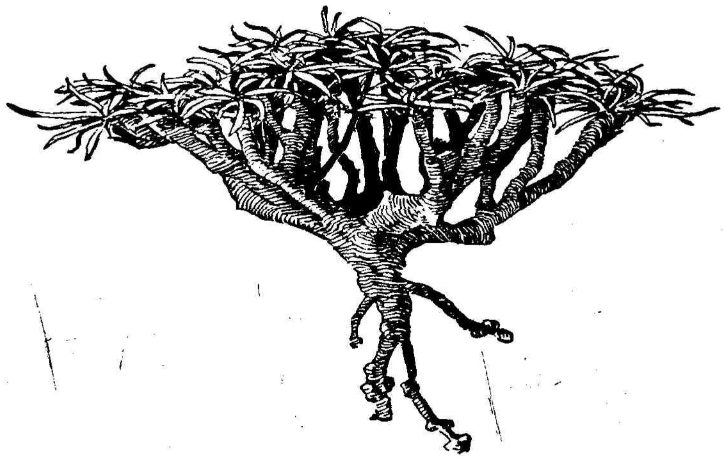


Fig. 45.—*Armeria maritima*, a typical perennial halophyte with rosette-like habit. ⅔ nat. size

as in Aster, or otherwise) are non-permanent structures. As the surface slowly rises, these plants hold their place by producing their successive rosettes of leaves at slightly higher levels. Commonly this adjustment to changing level coincides with branching of the original crown, so that the area occupied by the plant undergoes peripheral expansion (cf. fig. 45).

In this manner numerous perennials will be brought into strenuous competition with one another for the limited space available, and it is to be expected that sometimes one species and sometimes another will prove successful in the struggle, according as one or other is favoured by the particular conditions of the habitat. Though the elements of the struggle have yet to be ascertained, it is probable that such types of high

marsh as consist predominantly of Armeria (as on the Dovey estuary in Wales and elsewhere), or of Statice (as is so frequently the case in East Anglia), are examples of a survival of the fittest under the given conditions. At the same time, however, it has to be borne in mind that a like result (i.e. a relatively pure sward of a given species of plant) may in some cases arise in the absence of competition, when other plants for any reason are unable to establish, or when their seeds fail to invade the particular area.

Spergularia media differs somewhat in habit from the other species enumerated in that the cylindrical fleshy leaves are borne in whorls on spreading, straggling axes which arise from the summit of the subterranean rhizome. As these axes become bedded in, they in turn originate fresh branches in the same manner.

The Reproductive Methods of Salt-marsh Plants.—The annual plants, of which the Salicornias (*S. annua*, *S. ramosissima*) and *Suæda maritima* are the best examples, depend for their power of holding their place upon their huge seed output. When these plants die in autumn the seeds fall in the mud and become anchored by the filamentous Algæ (Rhizoclonium, &c.). Under cover of these they germinate in early spring, coming up in beds, thick like mustard and cress. Germination under this protection is considerably earlier and under more favourable conditions than on bare mud. Thermometers placed beneath the algal network on a cold day in March showed a mean excess of 2° C. over the temperatures given by simultaneous readings from other thermometers similarly placed, except that the algæ had been cleared away.

By no means the whole of the seeds are thus entrapped; many drift and are carried to a variety of situations. Thus if slabs of the soft, bare mud of creek bottoms be removed and placed under appropriate conditions, seedlings will often appear (Suæda, Salicornia), which under ordinary circumstances hardly ever establish on account of the high mobility of the mud.

These annuals are able to hold their own year after year even when embedded in a turfy matrix of the Salt-marsh Grass (*Glyceria maritima*). This they appear to do in virtue of their

power of early germination, by which the root zone of the turf is penetrated before the grass has aroused itself from its winter anæsthesia. In this connection the circumstances under which annual plants are sometimes able to carry on in non-maritime turf would probably repay investigation.

The halophytes other than annuals, whilst showing the highest capacity to hold their own and spread by vegetative means, are all of them, so far as our investigations go, satisfactory producers of seed. At the same time, in not a few cases, seed output tends to be concentrated in bumper years separated by series of years of low or moderate production. The cases of *Suæda fruticosa* (p. 116) and of *Spartina Townsendii* (p. 180) have already been referred to. Another case in point is *Obione portulacoides*, of which for years no seedlings can be found in particular localities, and then comes a year in which tons of fruits accumulate everywhere in the drift and seedlings are most abundant. Another well-ascertained case of a plant liable to bumper years is *Statice binervosa*. It is probable that the bumper years are accountable for the spread of these plants into fresh localities (cf. the case of *Spartina Townsendii*, p. 180), whilst the strongly-marked vegetative methods permit the newly-established seedlings to expand into tufts or clusters and thoroughly occupy the ground. The halophytes thus afford an example of the way in which the versatility of the life histories of the individuals enables them to invade and establish in new terrain, and then to occupy it in the most exclusive manner. It is not to be doubted that analogous relations are also to be found in the case of ordinary terrestrial plants.

The Developmental Phases of the Salt Marsh.—Whilst the individuals which collectively make up any natural vegetation are inevitably liable to change, those of the salt-marsh covering fluctuate to a pre-eminent degree. The pioneer plants, whether of a mud flat or of a sand-bank, endure only for a limited period, and as the conditions change the ground becomes suitable for the entry of other species which replace the pioneers, and in their turn are superseded by yet others. A vegetation thus undergoes progressive development, passing through a series of definite phases termed "successions", which lead to

a terminal succession, technically known as the "climax" vegetation. This is commonly the last and most enduring phase.

On the salt marsh such terminal successions include the Glyceria and Armeria swards, the Statice marsh, the Juncus belt, and doubtless others. The detailed history of development has been followed only in a few cases, and even in these we are for the most part ignorant of the causes which determine the several successions. Attention is only just beginning to be directed to the intensive study of the habitat, and little more has come to hand than the names of the species and the order in which they supplant one another in a certain number of instances. In the case of the salt marsh we know that these changes are accompanied by a rise in level, and this of course must mean increased drainage and a less amount of tidal immersion. These alone are factors which will react favourably on certain plants and unfavourably on others—plants being on the whole rather exacting in their water requirements. Whether, however, such changes are by themselves decisive, or whether, on the other hand, plants may not produce in the soil toxic bodies prejudicial to themselves, and thus indirectly favourable to the advent of the next succession, must remain for the present an open question (cf. pp. 63, 64).

The developmental sequence of a salt marsh is not necessarily obvious at a glance. Quite possibly the area visible from a given point is all in the same phase of development, i.e. is all in the same succession. The only chance in a case like this is the possibility that the remains of previous vegetations may be preserved below the surface still in a recognizable state—as frequently happens in peat bogs. Generally, however, different parts of the marsh are in different phases, and if these are present in sufficient numbers it will be possible, by listing the constituent plants, to arrange the phases in their order. All that is necessary then is to be certain as to which is the relatively initial and which the relatively final phase.

In a marsh undergoing local erosion by undercutting with a migration of its creeks, much of the eroded material is apt to be deposited as a bank on the following side of the creek whilst the advancing side carries on. If the creek continue for some

years advancing in the same direction, a series of banks are left in succession, side by side, that nearest the creek being the youngest. These banks commonly become recolonized by vegetation, and by comparing the vegetations of a series a close approximation is obtained of the various successions through which the marsh as a whole has passed.

It was partly in this way, and partly by comparing the changes in the vegetation of the individual banks over a period of six years, that the broad outlines of marsh development in the salt marsh at the Bouche d'Erquy in Brittany were elucidated. As the case is typical of the sandy type of salt marsh, and the history of the colonization of a single sand-bank provides an epitome of the colonization of the whole marsh, a short illustrated account will not be out of place here.

Colonization of Sand-banks in the Bouche d'Erquy.—1st Phase.—Banks of sand are deposited near points in certain creeks where the bank is being eroded by the meandering of the creek. The sand-bank illustrated here was oval in form, 20 feet wide at the broadest point, and 40–50 feet long. The position was such that the sand-bank was not covered at the lower neap tides. All the spring tides covered it, the highest ones with at least 6 feet of water. The flow of the water in the creek often reached a velocity of 3 to 3½ miles an hour.

The first flowering plants to appear on the bank were a scattering of two species of Salicornia, viz. the annual species, *S. ramosissima*, and the perennial, *S. radicans*. These plants on establishment at once accrete hummocks of sand, in much the same way as a Psamma tuft accretes an embryo dune (cf. p. 60); with this difference, that here water is the agent of transport whilst in the case of the dune it is wind. By August the hummock-forming plants have attained their maximum growth for the season, and the hummocks will likewise be at full size. On the approach of winter the plants of *Salicornia ramosissima* die, their skeletons remain in place till the following spring, and serve to shelter the hummocks that have accreted around them. Ultimately these plants disintegrate and weather, and their hummocks, no longer sheltered by an organic nucleus, are dispersed. Other seedlings of the same species establish

each spring at other points on the sand-bank, but from the nature of the case their hummocks are ephemeral, and make no conspicuous permanent contribution to the relief of the marsh.

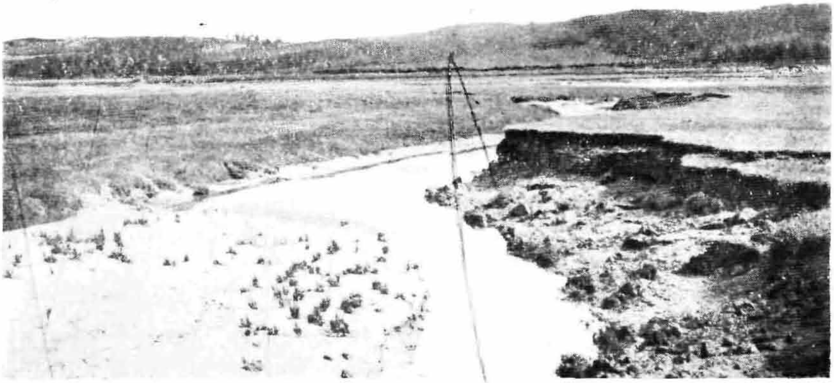
The *Salicornia radicans* hummocks behave quite differently. After the winter rest the plant increases in size, and the hummock undergoes a corresponding extension. It is characteristic of *S. radicans* in this position that it not only grows in height but also spreads laterally to form a belt placed at right angles to the flow of the current (cf. the black bands in fig. 46, A). The result is that the hummocks show marked expansion. At this stage they are pyramidal in form, 8 inches to 1 foot in height, and rest on a kite-shaped base, occasionally reaching 7 feet in length and 4 feet in width (Plate XIX, 2).

These *S. radicans* hummocks are the fundamental units from which the future relief of the salt marsh is built up.

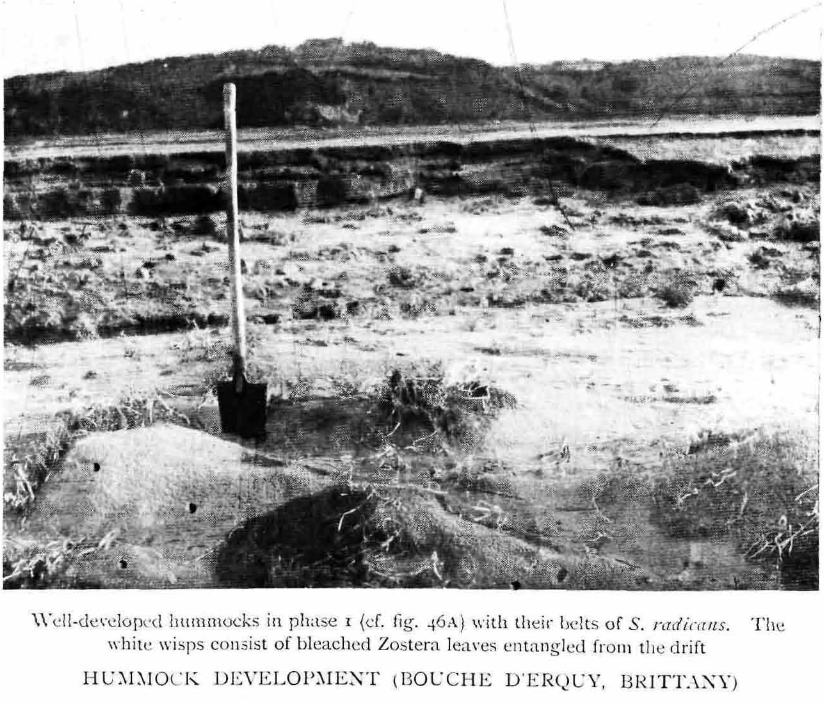
Sand-banks may remain bare for a number of years, or they may undergo primary colonization almost at once, according to the facilities for the bringing and attachment of seeds. The presence on the sand-bank of a plexus of the alga Rhizoclonium is an essential factor in anchoring the seed and sheltering the seedlings in the early stages.

2nd Phase.—The beginning of this is marked by the colonization of the hummocks by other species of halophytes. By far the most important of these is the grass *Glyceria maritima*, but *Suæda maritima*, *Obione portulacoides*, &c., settle in at the same time. The hummocks, which are at first vegetated in patches (as in fig. 46, A), become entirely clothed with vigorous turf in the course of one or two seasons (fig. 46, B and C), and as an immediate consequence expand in all directions by the incorporation of particles of sand between the shoots and leaves of the plants. This expansion, which continues as long as the hummocks are fed with sand by the flowing tide, leads to adjacent hummocks coalescing to form continuous turfy hummock systems (as in fig. 46, C), which are added to the general sward of the marsh as the creek abandons the original sand-bank in its further meandering.

Two stages of the area charted are shown in the photographs



Part of Bank charted in fig. 46 photographed three years before Chart 46A was made; it shows the earliest phase of colonization by *Salicornia radicans*, which in places has already orientated itself transversely to the current



Well-developed hummocks in phase 1 (cf. fig. 46A) with their belts of *S. radicans*. The white wisps consist of bleached Zostera leaves entangled from the drift

HUMMOCK DEVELOPMENT (BOUCHE D'ERQUY, BRITTANY)

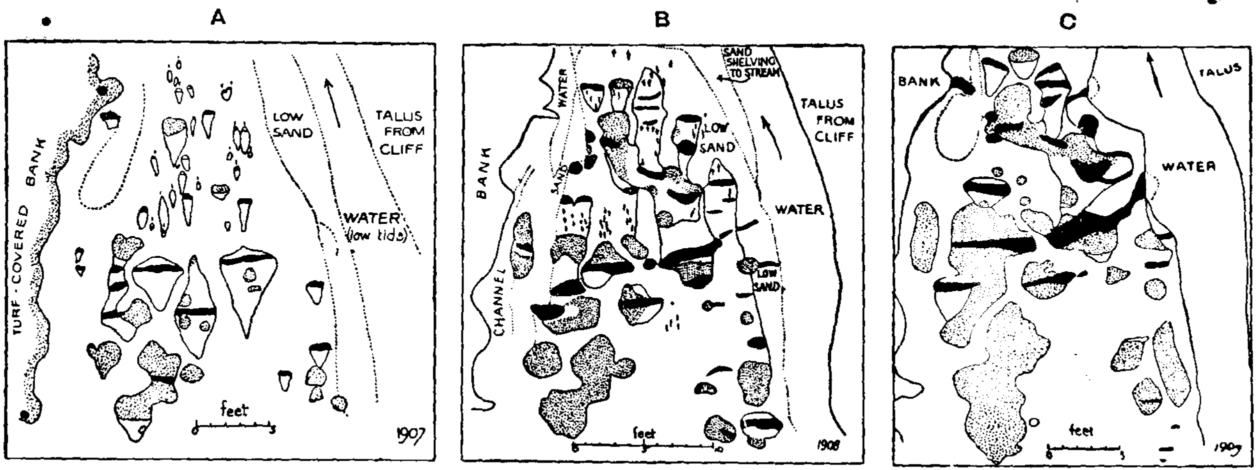


Fig. 46, A, B, and C.—Serial Charts of same 25-foot square surveyed in the successive years 1907, 1908, and 1909 to show hummock formation on a bare sand-bank by *Salicornia radicans*, and the subsequent colonization of these hummocks by *Glyceria maritima*. Black belts, *Salicornia radicans*; dotted areas, *Glyceria*. Vertical strokes in A and B are annual Salicornias with small, non-persistent hummocks. Occasional colonists in B and C are omitted. The summits of the largest hummocks rise to about 1 foot above the general level. The arrows point downstream. An earlier stage of the area is shown in Plate XIX, 1. Scale 1/140.

on Plate XIX. The upper picture shows the hummocks beginning in 1903, the lower a detail of a later phase corresponding to fig. 46, A (1907).

In many cases the original sand-banks remain separated by low depressions which often retain water after the tide has ebbed. Where growth has been very regular, and the original sand-banks were laid down side by side to form a point of land following the advance of the creek, the depressions are curved and parallel, and when filled with water at once betray the origin of the relief. (Cf. the three advancing points, Plate XVI, 1, p. 176.)

In the later stages of this grass-hummock phase two antagonistic tendencies are manifest. The ground colonized being undulating and hummocky, there will be certain lines which the tide will follow invariably as it swills over on to the marsh from the larger creeks. These natural irrigation lines take the form of shallow channels, a few inches wide, generally bordered at Erquy by a bright-green form of *Salicornia ramosissima*. Now water flowing along defined lines over undulating terrain will exhibit the phenomena appropriate to stream flow, and will tend to undercut the banks, and to bring about a migration of its channels. At the same time the exuberant vegetation as a whole will conflict with this tendency, and where the cutting power of the water is small will often obliterate the channel altogether. The channels thus tend to become discontinuous, the surviving portions taking the form of chains of "pans". These pans are depressions largely bare of vegetation and having no outlet; the water circulates in eddies as they fill, so that pans are apt to widen or enlarge irregularly. In the aggregate quite an appreciable area of the marsh may be occupied by pans.[1]

The above much-abbreviated account of the development of a sandy salt marsh should suffice to show that the process is a complex and continuous one, and that all the stages are closely interrelated. Apart from the interest which attaches to any related series of natural phenomena, the matter has a bearing on the exploitation of the salt marsh. Thus, when bare

[1] Cf. R. H. Yapp and others, "The Salt Marshes of the Dovey Estuary", *Journal of Ecology*, Vol. V, p. 65, 1917.

Artificial inoculation of *Salicornia radicans* on a bare sand-bank; hummocks beginning

Cart-tracks colonized by Salicornia and *Suæda maritima*

BOUCHE D'ERQUY, BRITTANY

sand-banks are deposited in the beds of channels, several years may elapse before seedlings of *Salicornia radicans* become established and the hummock stage is inaugurated. These interruptions can be avoided by planting *S. radicans* dug from some other part of the marsh. Such an experimental plantation on a sand-bank in the main channel of the estuary is shown at Plate XX (above), after the clumps had settled in. In due course hummocks were formed, but this particular experiment was destined to be overwhelmed ultimately, owing to flood water from the land after rain undercutting the entire bank on which the original plantation had been established. In another creek a similar plantation survived. The hummock system charted in fig. 47 arose in two years from the date of planting the sandbank with *Salicornia radicans*, and is identical in all respects with a naturally-produced system of hummocks.

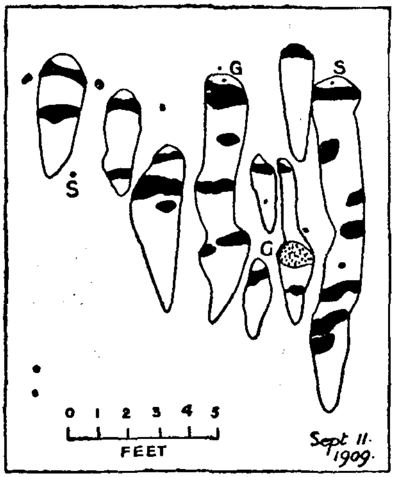


Fig. 47.—Chart of *Salicornia radicans* Hummocks, showing beginning of secondary colonization two years after plantation made. Black belts = *S. radicans*; G = *Glyceria maritima*; S = *Suæda maritima*. Other dots represent isolated Salicornia plants.

The phenomena of these sand-banks are constantly in operation on the bare flats towards the mouth of the estuary (Bouche d'Erquy), where the colonized and bare unstable areas abut. Roughly a zone some 10 feet wide of the latter is occupied each year by the pioneer plants. The chief obstacle to rapid colonization in this region is mobility of ground, for where this is overcome by accidental causes, colonization proceeds apace. Thus carts sometimes cross a corner of the marsh, on their way to and from a place in the dunes where sand is dug, and in the ruts so formed a vegetation springs up forthwith (Plate XX, below). The rut acts as a trap which catches the drifting seed, and the soil below the rut is consolidated by pressure so as to give the

plants a foothold. A striking manifestation of this consolidation is sometimes to be seen at places where the uncompressed soil has weathered out, leaving the consolidated soil beneath the rut as a ridge standing out in relief.

By no means every sandy salt marsh is colonized quite in the manner described. Frequently the species of plants are not the same, though they play substantially the same parts. For instance, near Silverdale, in Morecambe Bay, and elsewhere, *Glyceria maritima* is the actual hummock-building pioneer (phase 1), and is followed by the grasses *Lepturus filiformis*, *Agrostis alba* v. *maritima*, and *Festuca rubra* v. *pruinosa*, together with Plantago and Armeria. (Cf. Appendix V, p. 269.)

Muddy Salt Marshes.—There are different consistences of mud, and this character has a marked influence on the nature of the pioneer colonists. Soft mud and relatively hard mud, however, contrast with sand, in that they show little tendency to develop hummocks in the manner described in the preceding pages. The material does not collect rapidly at particular spots as in the case of sand. Where hummocks are a very prominent feature on mud, they are in part residual, i.e. have been exaggerated by the cutting away of the intervening ground. (See also p. 195.)

Soft mud[1] is relatively more obstinate to colonization than firm mud—(1) because it is not easy for many otherwise suitable species of plants to get a proper foothold; (2) because its waterlogged state retards the diffusion of oxygen needed for the respiration of the embedded parts of the plants. Consequently it is not surprising that the pioneers on soft mud are usually specialist plants capable of dealing with these peculiarities of the habitat. By means of creeping rhizomes rooting all along, they get a good hold of the ground, whilst, by the provision of an ample system of internal lacunæ throughout the plant, the oxygen dissociated from carbon dioxide in the process of chlorophyll assimilation is able to diffuse readily to the embedded portions of the plant.

The commonest pioneer on soft mud is the Grass-wrack

[1] "Soft mud" may be defined roughly as mud into which the foot sinks ankle-deep or more; "firm mud", not beyond the sole of the boot.

(*Zostera marina* and *Z. nana*), a curious plant with ribbon-like leaves and creeping rhizomes. The latter form a dense plexus, holding the plant in place in the mobile ground. Propagation is carried out freely by seed in the localities we have examined, and this is doubtless supplemented by fragments of rhizome broken loose in heavy weather. Zostera, which occupies the lowest zone of all phanerogamic halophytes in Britain, is remarkable in being one of the very few plants whose flowers are adapted to cross-pollination by the agency of water.

When the mud has been sufficiently consolidated, Zostera may be followed by one of the annual species of Salicornia, e.g. *Salicornia annua*. Henceforward the history of development follows substantially that described below for firm mud.

Another plant which follows Zostera is *Spartina Townsendii*, and we should not be surprised to hear that it could colonize soft mud even in the absence of this plant. It is adapted to the habitat both by its creeping rhizomes and by its ample lacunæ. The history of the spread of this remarkable grass in the Southampton region and its importance as a land builder have already been fully described (pp. 175–183). Another plant often colonizing soft mud is *Scirpus maritimus* (Plate XVIII, p. 180, marked *Sc.* in upper photo.). In some districts (e.g. Poole Harbour) it is cut for thatching.

Firm mud, generally consolidated by the action of Algæ, sooner or later will show a thin scattering of Salicornia (e.g. *S. annua*). In successive years this covering, renewed annually from seed, becomes more and more compact, until a pure sward of Marsh Samphire, the first "succession" of the series, is established.

If the area be at all extensive the marsh will be irrigated by creeks, the original lines of which are frequently laid down in advance of the appearance of the vegetation covering.

Where flats undissected by creeks and previously bare produce rather suddenly stretches of Salicornia, the vegetated areas become appreciably convex by accretion within one or two years. The tidal waters running over such areas naturally follow the less densely vegetated and slightly lower regions between, which thus become the natural primitive creeks. In

such cases the lines of irrigation are determined more by the accidents of colonization than by any special pre-existing features in the relief.

On salt marshes where Fucoids (e.g. *Fucus limicola*) play an important part, these plants are especially conspicuous at the lower levels, and their occurrence synchronizes with the pre-Salicornia phase and persists into the Salicornia phase itself (Plate XV, p. 172, below). As the level rises and other halophytes come in, the Fucoids tend to disappear, or at best to survive only locally. During the period of their dominance, however, they are of great importance as accretors of silt (cf. p. 172).

In due course the Salicornia phase gives place to the next succession, and this is by no means the same in all cases. It is possible also that the Aster is one of the plants liable to become prominent in salt marshes undergoing down-grade changes or retrogression, and if this be the case a certain difficulty will be found in determining the status of an Aster marsh when its previous history is unknown. Although the detailed study of plant assemblages is relatively recent, more attention has been given to their progressive development (i.e. first establishment to climax) than to their degeneration. Sometimes the history of a vegetation comes to an end suddenly by erosion, as when a marsh is undercut by a meandering creek, whilst in other cases a vegetation may slowly go back in its footsteps, with variations. It is these latter retrogressive phases, whether in salt marsh or other vegetation types, that have been so little studied, and which are liable, in the absence of more precise data, to be confounded with true "successions".

In other cases, and this is the more typical history of muddy salt marshes, the Aster enters only in moderate degree, and is accompanied by a variety of halophytes, such as *Plantago maritima*, *Spergularia media*, *Statice Limonium*, Armeria, Triglochin, and *Glyceria maritima*. The last-named grass where present tends to form a plexus everywhere, and here, as in more sandy marshes, is a most important component. Under the sway of these perennial plants the marsh grows up into typical high marsh or "mixed salting", the Salicornia being

gradually crowded out, or surviving only in special, favourable spots.

On different parts of the coast the mature phases of salt marshes wear a distinctive facies. Sometimes it is Sea Lavender (Statice), sometimes Thrift or Sea Pink (Armeria) that is the outstanding element, whilst in other cases the turfy Glyceria matrix holds its own in relative purity.

Another plant frequent on salt marshes is the Sea Purslane (*Obione portulacoides*), a low prostrate bush with glaucous leaves, which commonly outlines the banks of creeks. Occasionally Obione spreads over the marsh from its ordinary station, overrunning and obliterating most of the other plants (Pl. XVI, p. 176).

Indeed, no two salt-marsh systems are quite equivalent when their plant coverings are analysed in detail. To attempt to explain these things, which depend on many factors, is impossible at present. Food and climatic differences are no doubt partly accountable, giving this or that plant a relative advantage over its competitors, whilst what is termed the "historic factor" —whether the agents of distribution have brought a given plant on to the scene sooner or later—must also have an important bearing. It is probable that a certain species of plant will have its best chance of establishing itself in a marsh at a certain stage in the development of the marsh, and if at the critical moment its seed be not forthcoming the marsh will continue to develop without it, and this result will not be affected by any belated supply of seed.

A very characteristic region of the salt marsh is the Juncus zone, which commonly occurs on the rising ground adjacent to the dry land or sand dunes backing the marsh. *Juncus maritimus* and the lower-growing *Juncus Gerardi* are the characteristic species, and associated with these are other halophytes, of which the Sea Milkwort (*Glaux maritima*) is the most usual. The Juncus zone is overrun by the higher spring tides only. It is most tenacious and resistant of erosion, and doubtless has considerable mechanical value in screening from scour whatever ground happens to border the marsh, and is especially useful in protecting the foot of such readily erosible terrain as sand dunes. Except where salt marshes are in

process of occupying new frontages the phases antecedent to the Juncus zone are not readily observed, though in cases that have come under our observation *Glaux maritima* was the pioneer plant. In view of the mechanical value of the Juncus zone in protecting the shore, fuller knowledge of the circumstances which control its development is much to be desired.

The Process of Accretion.—The foregoing account of the salt marsh and the details of its structure and development show that the vegetation covering plays a part both in the accretion of silt, and in resistance to erosion, the importance of which it would be difficult to exaggerate. At every level on the shore of sheltered inlets and estuaries plants establish between the high-water marks of the neap and spring tides. These vegetated areas form the collecting surfaces where silt is retained and permanent rise in level effected. Indeed, this co-operation of plants is practically universal where new land is being organized from supplies of mud or sand transported by the agency of water currents and wind. The vegetation contributes to the operation in two ways. Firstly, it provides a shaggy covering to the ground which entangles the silt upon and between the plants; secondly, by its inherent capacity to grow through these increments (anarhizophytism), the newly-won material is bound and fixed by the roots and underground stems of the halophytes. In other words, the silt forms the soil and the plants keep pace by their growth. At the same time the vegetation of previous years becomes in large part buried, thus enriching or manuring these soils with organic matter, and accounting for one factor in their recognized boundless fertility.

The following unpublished data derived from the Blakeney marshes illustrate the foregoing: these determinations, together with those of garden soils, were made for us by the late Dr. S. M. Baker, whose great knowledge of salt-marsh algæ was always freely placed at our disposal.

The table gives the losses undergone on ignition by the surface soils expressed as percentages of their original dry weights, and may be taken as giving an approximate clue to the organic matter present.

Nature of Marsh Vegetation.	Mean Loss on Ignition, per cent of Dry Weight.
Mature salting with Obione	21.39
Pelvetia-Salicornia marsh	17.85
Young marsh under *Fucus limicola* ...	8.39
Mud with *Vaucheria Thuretii*	7.30
Mud with *Microcoleus chthonoplastes* ...	4.86

For comparison with these results the corresponding losses n dune sand fixed by the moss *Tortula ruralis* was 0.69 per :ent; and in a sample of heavy clay loam in a kitchen garden nanured in spring the following percentage losses on ignition were determined, six months after manuring: Runner beans, :3.32; potatoes followed by cabbage, 16.26; maize with leaf nould, 21.55.

We find generally that the soils of Obione saltings are very ·ich in organic matter; so, too, is the soil of a large Salicornia narsh, the surface of which is densely covered with the curious, ıon-attached fucoid *Pelvetia canaliculata*, forma *libera* (cf. p. 227).

The three other determinations in the table are of interest, ıs they refer to quite young marsh soils occupied by various species of Algæ. The source of the organic matter in these :ases is, doubtless, the filaments and thalli of the Algæ which ıave become buried in the ordinary process of accretion.

Mud and sand-banks, of course, often arise without the intervention of plants, but these are turned over by every tide and ıre liable to be shifted from one place to another with changing vinds and currents.

The process of warping, too, as practised in the Bay of Fundy marshes (and presumably elsewhere), is also stated to be quite independent of the presence of vegetation.[1] This shows hat the marsh reclaimer is able by technical skill in his art to lispense on occasion with the services of plants.

It is the power which plants have of organizing and retaining ground which gives them value in this connection, and makes it lesirable to ascertain in detail the part which each species of

[1] See Ganong, "Vegetation of the Bay of Fundy Marshes", *Botanical Gazette*, Vol. XXXVI, ı. 167, Chicago, 1903.

plant plays in its own particular zone. For, armed with this knowledge, it becomes possible by artificially introducing a given species at the appropriate moment to hasten the passage of one phase into the next, and thus promote accretion without pauses or delays. Should this practice be adopted we should look forward to a time when, by vegetation methods, combined with temporary engineering constructions for protection from scour and the control of currents, tidal lands would mature for final reclamation not only more rapidly than is at present the case, but also in topographical distribution conveniently for the purpose. It has been a principal object in writing this book to emphasize the importance of plants from an engineering point of view.

The Measurement of Vertical Rise in Level of Salt Marshes.—Information on this subject is hard to come by, except in districts like the Isle of Axholme in N.W. Lincs, where the operation of warping is practised. Warping consists in admitting tidal waters heavily charged with silt on to banked lands which lie below high-water mark, and allowing the silt to deposit. By continuing the operation for a period of two or three years (two tides a day for some ten days per month) a thickness of 1, 2, or occasionally even 3 feet of silt is thus deposited, the thickness depending on the richness in silt of the tidal waters employed and the skill with which they are led to and distributed over the lands to be warped.

On the Blakeney marshes a few experiments extending over a period of two and a half years have been made, and as the results are sufficiently numerous and consistent to be accepted as reliable a few of them may be quoted here. It will be understood, of course, that these are records of the natural silting process unassisted by any of the artifices of warping, and that the tides, unlike those of the Humber, are not heavily burdened with silt. The texture of the deposit is fine, and sand is practically absent.

Example 1.—High salting bearing Obione covered by the higher spring tides, say 120 tides a year. Rise of level in 2 years 5 months, 0.4 inch. At this rate the rise would be 1 foot in 72 years.

Example 2.—Low marsh which in 1910 bore only a thin scattering of *Salicornia annua* (Marsh Samphire), *Fucus limicola*, and a few plants of *Aster Tripolium*. Since 1910 the vegetation has rapidly increased, until at the present time (1917) the Salicornia has reached maximum density and Asters are everywhere abundant. Other halophytes are also making their appearance. The marsh is covered by almost every tide, say 700 a year. Rise of level in 2 years 5 months, 2.5 inches under Salicornia, 3 inches under *Fucus limicola*. At the latter rate the rise would be 1 foot in 9½ years. This is the largest result yet obtained.

Example 3. — Salicornia-Pelvetia marsh, covered by all spring tides (240 tides a year) and in the centre by the higher neap tides as well (making about 600 tides a year). Determinations were obtained at stations every 10 feet along a line crossing the long axis of the marsh at right angles, i.e. from bank to bank.

The rise in level after 2 years ranged from 0.2 inch at the edge to 1–1.25 inches at the centre, the intervening stations, according to their position, giving readings intermediate between these extremes. At these rates of silting the rise in level ranged from 1 foot in 120 years, at the edge, to 1 foot in 19 years at the centre. The distribution of silting here is in conformity with the fact that young marshes are generally concave (i.e. slope down gently to the creek), whilst old high saltings are practically dead level.

We are indebted to Dr. M. C. Stopes for organizing the series of accretion stations (in August, 1914) in Example 3, and to Dr. E. J. Salisbury and Mr. B. K. Hunter for measuring up the results (in August, 1916).

The above, and other preliminary results that have come to hand, all point to the importance of the number of tidal immersions in determining the amount of silt deposited. Whilst this is no doubt the most important factor, we are impressed with the high efficiency of the embedded *Fucus limicola* in promoting accretion. In Example 2 (and other cases bear out these results) ground with Fucus grew 0.5 inch more in 2 years 5 months

than similar ground close by carrying *Salicornia annua* only. This difference is roughly equivalent to a vertical rise of 1 foot in about 60 years.

The method by which these results were obtained was not that of placing the levelling staff on the same spot at convenient intervals of time and comparing the readings with a fixed bench mark. The expansion and contraction to which tidal soils are liable and the varying state of muddiness of the surface render such a method quite unreliable for the determination of small increments. Driving a peg and measuring the length projecting from the surface is also open to objection, as the peg may be trodden on, moved, or pulled out of the ground, and in any event is liable to promote scour and erosion in its immediate neighbourhood, or to collect seaweed and other drifting matter.

We lay a new surface closely similar in texture to the actual ground, harmless to vegetation, and of a distinctive and permanent colour. For this purpose we experimented with a series of the well-known coloured Alum Bay sands, from which the plum-coloured sand was finally selected as being quite unlike any silt occurring in the Blakeney area.

The method of procedure was as follows:—

Places or stations for accretion observations having been selected, e.g. at measured distances along a straight line joining two known points, the coloured sand, previously pulverized in a mortar and passed through a sieve of about 50–60 meshes to the inch, is laid on the ground in circular areas, 6 inches in diameter, to a thickness of 1 millimetre. As a rule at each point these areas are laid in duplicate, right and left of the line and touching one another. That the coloured sand may lie evenly on the ground, and that losses by wind may be avoided, the sand is applied from a conical Cerebos salt-cellar of the ordinary pattern on to a sieve (6 inches in diameter and having 30 meshes to the inch) lying on the ground. The frame of the sieve should have at least 2 inches of freeboard, under cover of which shelter from the wind is obtained during application. From the sieve the sand falls on to the ground.

For additional assistance in rediscovering the area after lapse of time three little pegs in the circumference of each area should be driven into the ground till almost flush with the surface. Even if entirely bedded over by accretion when the time comes for re-examination the pegs can generally be located by probing. For the recovery of the stations it is of great importance to mark the ends of the line by visible posts, and to measure and book accurately the distances.

To determine the amount of accretion a vertical slice is cut out from the area and measurement made from the upper surface of the coloured layer to the new surface of the ground. It is essential that the slices so measured be cut vertically, otherwise the results are exaggerated. If the holes made in removing these slices be filled in with mud the same area can be used on future occasions. It is well to avoid replacing the actual slices cut out, as the pigmented zone is difficult of adjustment.

On bare ground or ground containing algal filaments there is a liability that the first tide may wash away the coloured area. To avoid this another device is employed. A perforated sheet of metal 6 inches in diameter is laid on the area, the perforations following a convenient pattern, e.g. a doubly-outlined Geneva cross, with one limb parallel to the line of direction. Two-inch pins with coloured glass heads are pressed through the holes into the ground, and when the sheet of metal is removed the heads of the pins are made flush with the surface. Subsequent slicing of the area will show the height of accretion above the heads of the pins.

To fix down on the soil permanently a disk of metal, &c., would give a false result, because it would interfere with the free colonization of the area by Algæ or other vegetation.

CHAPTER XI

Miscellanea (Cliffs, Rivers, Channels)

There remains for consideration the special treatment of certain particular types of terrain to which no detailed allusion has yet been made. These include cliffs by the sea, the banks of creeks and tidal rivers, stony river beds liable to sudden floods and migration of channel, &c. Of these by far the most important in practice are the sea cliffs, in view of their liability to erosion by the sea.

Sea Cliffs.—Two principal causes combine in the destruction of cliffs, viz. sub-aerial agencies and the undercutting of the base by direct wave action.

The sub-aerial agencies include especially land drainage, percolation, frost, and chemical action. Where these operate in the absence of wave action the face of the cliff tends to assume the angle of repose proper to the materials. By appropriate treatment, especially of the drainage from the land, such cliffs may be rendered relatively stable, for under these conditions a spontaneous vegetation will arise, protecting the surface and minimizing or obliterating all liability to erosion from rain impact and the like. The inherent tendency of all sloping ground to undergo a certain amount of slip cannot be entirely eliminated, as all hygroscopic movements of the soil must under the action of gravity tend in the downward direction. Apart, however, from special cases in which the soil becomes viscous with imbibition of water, sloping ground at the angle of repose may, if properly covered with vegetation, be regarded as substantially at rest.

The frontages where Tertiary deposits abut on an exposed

coast-line or estuary are peculiarly liable to destruction, by reason of the double effect of under-scour and the simultaneous pressure forwards, in the manner of an avalanche, of the plastic clays of which they are largely composed. Frequently veins of sand or gravel are sandwiched between the clay deposits, and such veins are denuded by rain or sea wash. Even without the predisposing cause of undercutting at their base, such cliffs of clay tend by gravitation to collapse.

The New Cross railway cutting is an object lesson in this respect to Londoners. Ever since the construction of this length of the Brighton Railway seventy years ago, the clay slopes running two or three miles south of New Cross have been in a condition of unstable equilibrium. The gradient of the line being heavy, and the oscillation due to express trains extreme, these banks were until comparatively recently actively mobile. Their movement has been arrested in the main by cutting drainage grips at the most dangerous spots, and either burning the clay in such grips, or laying block chalk in them to enable the land water to get away.

The coast-lines at Herne Bay, Yarmouth (I.W.), and Walton-on-the-Naze are notable instances of the danger of the movement of what in Essex is locally termed "blue slipper". At Herne Bay one of the authors saw a field of turnips, which had slid bodily from the crest of the cliff to the shore, the turnips growing undisturbed in their new habitat.

The vagaries of coastal landslips often appear inconsequent. Telford's practice in building reservoir embankments was to mix with his puddle clay clean gravel, with the object, by adding weight, to prevent its tendency to slip. The puddle clay of a dam is of necessity absorbent of water, and it is upon this saturation that its weight and water-holding properties largely depend. Frequently, in order to economize in the mass of materials used in the construction of a reservoir embankment, a thin hearting of puddle clay is weighted with stone or concrete blocks, pitched on both sides to prevent the spreading and settlement of the clay. The true cure for a tendency to slip in the design of a clay structure, is not to attempt to lay out walls at a steeper inclination than that of the angle of repose of the

material employed. Sea and river walls in the Thames estuary are mostly laid out at an inclination of 2 to 1 on the outer face, and 1½ to 1 on the inner face where stiff puddle clay is obtainable. Many plastic clays will not stand at anything like so steep an inclination, 5 to 1 or 7 to 1, or even flatter still, being often necessary to stability. One of the most potent agencies in conserving artificial slopes is that of systematic planting, the close network of roots of the plants creating a mat of immobility.

It frequently happens that landslides occur with great suddenness, and apparently long after predisposing causes should have ceased to operate. Such subsidence is in the main due to the underground passage of water of percolation. An area of soft silt underlying a mass of clay may remain for a long period in a condition of relative stability, owing to the incompressibility of its liquid constituent. As its moisture is gradually reinforced by percolation, it slowly develops the attributes of a semi-liquid body, and the varying pressures of the superincumbent earth cause its displacement, producing lateral and vertical stresses, until the equilibrium of the overlying strata is disturbed. The resistance of friction, due to masses of soil over such a cushion of semi-plastic silt, is ultimately overcome, and a landslide results. This action is repeated, it may be at considerable intervals, periodically, as the liquidity of the subsoil becomes such that it follows the laws of hydrostatic equilibrium. To counteract this action, ample drainage to check the tendency to the formation of subterranean pools of semi-liquid slurry is the first requirement. Rats and rabbits infesting a bank, by disturbing its superficial resistance to percolation, may set up areas of potential under-surface slip.

The infinite variation in the physical economy of the constituent materials of earth banks renders generalization difficult and formulæ precarious. Mr. W. Airy's remarks on the variability of clay resistance are of interest in this connection:[1]—

"He exhibited a little rough machine he had used for testing earthwork and taking the cohesion of the ground. The block of wood might be taken to represent a block of raw clay taken out of a cutting. There was a common lever-balance, and a couple of movable cheeks were fitted into chases cut in

[1] *Proc. Inst. C. E.*, Vol. LXV, p. 188.

the sides of the clay block; and the clay having been rammed in a box so that it could not move, weights were put in the scale until the head was torn off. After subtracting the weight of the piece that was torn off, and measuring the area of the cross-section that was broken, the constant of cohesion was determined. For the constant of friction he arranged a certain number of blocks of the same clay in a tray, and scraped them off smooth; then he had another block of clay with a smooth surface which he put on it, and then tilted the tray until the loose block slid; that gave the coefficient of friction. He should like to refer to the exceedingly wide range of tenacity shown by different kinds of clay. In one set of experiments with ordinary brick loam, that clay gave a coefficient of cohesion of 168 lb. per square foot, and a coefficient of friction of 1.15. With some shaly clay out of a cutting in the Midlands, he had found a coefficient of tenacity of 800 lb. per square foot, and a coefficient of friction of 0.36. That was a very wide range, but it was only a part of what was actually to be found in practice."

In respect of the protection of the toe of a clay embankment against the danger of wash, the practice in the construction of reservoirs in India is of interest. Pitching is carried in such "tanks" or reservoirs to a level of about 2 feet above the anticipated maximum wave wash. The thickness of pitching used for this purpose in feet is taken as a mean at

$$0.7\sqrt{\text{fetch of waves in miles.}}$$

In practice it varies from 6 inches at the bottom to 18 inches at the top of the highest dams. At the crest of the stone pitching, thus forming a wave breaker, there is usually a step of 9 inches in the pitching of the slope of the tank. The object of this break in contour is to check the run of the waves up the slope.

Undercutting by the sea is the serious cause of cliff erosion, and its degree is closely related to the texture of the material forming the base of the cliff. Where this is friable, as commonly on the East Coast, the falls of cliff are both extensive and frequent.

Protection from this class of encroachment is obtained in two ways: (1) By fortifying the cliff base against erosion by engineering constructions, such as sea-walls, breastworks, and the like, the cliff base is enabled more effectively to resist the direct attack of the sea. (2) Indirectly, by bringing about the accumulation, by natural methods, of obstacles which keep the

sea from working on the cliff base. In other words, causing beach materials (shingle, &c.) to collect so that the high-water mark is set back. This result is commonly effected by means of groynes, which both catch and tend to retain the travelling drift.

Artificial Dumping.—There are many localities where, by means of artificial dumping of shingle, a threatened coast-line may be economically conserved; in fact, there are few spots where a judicious application of this method would fail to result in permanent protection, provided simultaneously a system of groyning were carried out.

Such dumping has not, however, been resorted to in many instances. At Hove the sea-wall enclosing the Lawns was threatened, immediately after its erection, with destruction by under-scour. The expedient of depositing along the front some of the surplus shingle encroaching on the port of Shoreham was resorted to, with complete success. Similarly, at Newhaven, the low-lying eastern frontage of the harbour was rendered permanently secure by bringing shingle from the west side in railway trucks and tipping it on that foreshore, a scheme of groynage being also carried throughout. All that is really required is at high water to discharge the shingly soil of dredging operations from hopper barges as near the coast-line as practicable. If such works are judiciously carried out, the sea washes up and redistributes the material so dumped to the best advantage as a protection.

Some ten years ago the condition of the frontages of Lowestoft and Pakefield was desperate, the inroads of the sea being of an alarming character, and expenditure on the fronts an overwhelming burden on the local bodies concerned. Simultaneously a new Herring Basin was constructed at Lowestoft. The dredged material from this basin, which consisted mainly of clean shingle, was taken to sea and deposited in deep water. Had it been brought alongshore and deposited, in all probability the problem of the defence of the wrecked coast-line would have been made good at comparatively small cost. It is in the power to enforce combined operations of this nature that the utility of a central organizing authority becomes self-evident. There

are many localities, such as Dungeness and Orfordness, where shingle exists in boundless quantities, and an insignificant fraction of such accumulations, if judiciously distributed along threatened strands, would render them immune from destruction. The multiplicity of conflicting authorities, coupled, in many instances, with no specific power to act, often prevents such a policy being adopted. The result is that valuable land is washed away, or works of enormous cost inaugurated, when, as at Lowestoft, a simple remedy was immediately available and disregarded.

Even halophytic vegetation alone is unable to operate advantageously on a crumbling cliff base, because as a rule the degree of mobility is too great for its establishment. At the same time, when material collects at the base of a cliff, whether alongshore drift or talus, it should be planted, to render its removal more difficult. In exceptional cases, where sand blows, Marram Grass can be used and the formation of low sand dunes promoted at the foot of a cliff.

In very many cases of falling cliffs no protective measures are taken till some valuable building or other property is threatened with destruction. Under these circumstances, both the top and foot of the cliff will probably need immediate attention—drainage and planting in the case of the former, protection in the latter.

As an example, the case of the Parish Church at Lyme Regis, standing near the edge of a cliff of blue lias, may be given (fig. 48). The quotations are from the report of the engineers who were consulted in the matter. Their recommendations were carried out in 1911, and are reported as having given complete satisfaction.

"Owing to the serious inroad made by the sea on the cliffs and to the argillaceous nature of much of the upper portions, the ancient and historically interesting church of St. Michael is in a grave position.

"Within the memory of many now living there were two fields between the graveyard of the church and the edge of the cliff; these have not only disappeared, but a portion of the graveyard itself has wasted away.

"It is common knowledge that many human remains have been taken down with the slipping of the ground and have been washed away, and there is at the present time a brick vault projecting from the face of the cliff.

"The church now stands at a distance of but 80 feet from the edge of the cliff, and the playground wall of the old school but 12 feet.

"The inroad of the sea is one of the causes of danger to the church, and the foot of the cliff calls for attention; but the greatest immediate source of danger to the fabric is due to the condition of the upper part of the cliffs.

"The graveyard, for a depth of 10–15 feet, is composed of a light, porous material, through which the water has no difficulty in finding its way; the old excavations for graves permit the infiltration of water, and in some cases the gravestones and surrounding iron railings are tilted over where the water has washed out in its course the underlying ground.

"The water that thus sinks down converts the clay and shale into a slippery condition, and then finds its way out at the face of the cliffs, carrying much of this silty matter with it. This slips down until it reaches the uppermost limestone bed, where it oozes over the edge and falls into the sea.

"It is the loss of material in this manner that is the immediate cause of the close proximity of the top of the cliff to the church building.

"When the mixture of clay and shale reaches the limestone bed it has opportunity to become drier before entirely slipping over, with the result that a fresh supply, coming on with the return of wet weather, mounts up above this accumulation, and forms ridges behind which water collects in pools. The water in these pools in turn sinks in and finds its way out at a lower level, forming a slippery foundation for the partially dried portion.

"This action is again repeated, and the whole amount is thrown into the sea by the pressure of the ground behind."

For the arrest of the trouble and the protection of the church the following recommendations were made:—

"The first step to be taken is the insertion of rubble drains,

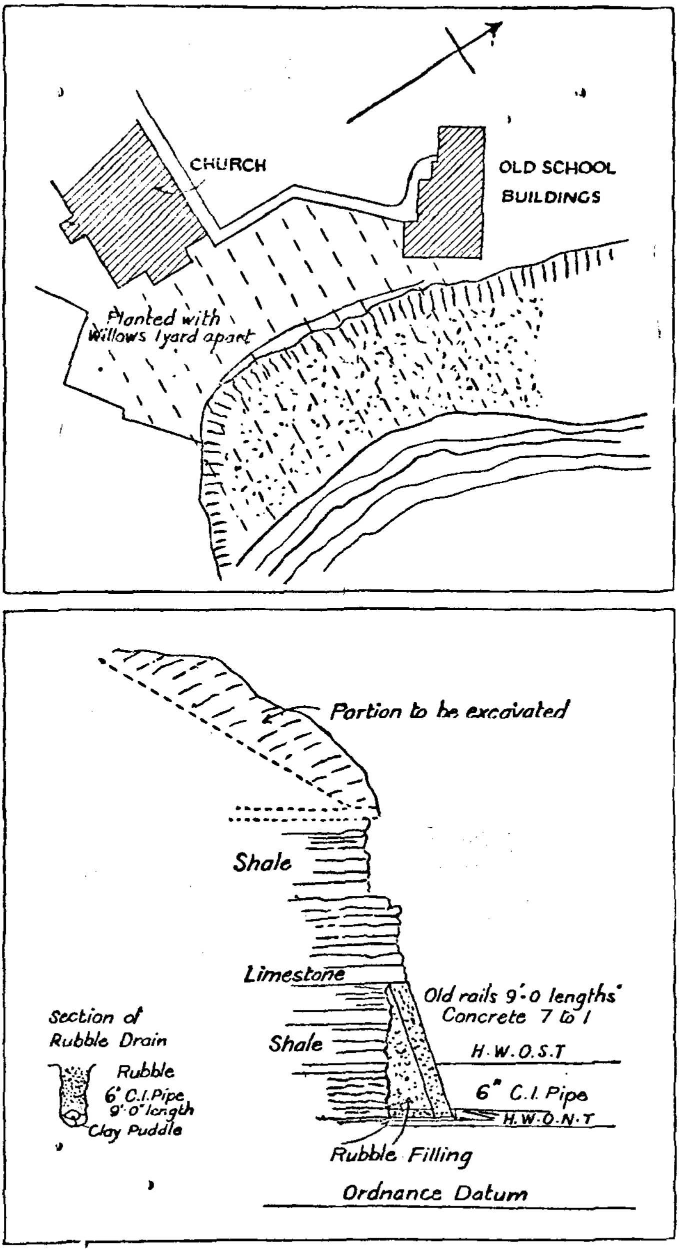


Fig 48.—Type Section of Cliff (Lyme Regis)

which will serve the double purpose of draining the churchyard and slopes and of assisting the latter to remain in position.

"These drains will consist of trenches filled with rubble, a pipe, of which the lower half of the joint is cemented, the upper half being left open, being laid on clay puddle throughout its length, and discharging on the beach.

"At the foot of the cliffs a reinforced concrete wall will be required, to prevent further erosion of the limestone beds by the action of the sea.

"This work will be carried from the end of the existing wall following the base of the cliff to a point 290 feet to the north. At the northern end a small groyne might be placed with advantage to accumulate shingle as much as possible in front of the wall.

"The shale beds above will be protected at intervals by masonry."

For the consolidation of the ground on the completion of the work the slopes at the top of the cliff were planted with willows at 1-yard intervals. Though these were entirely suitable for the purpose, they were gradually replaced by a miscellaneous assortment of garden shrubs, which, proving unsatisfactory in the position, have been discarded and willows once more reinstated.

The object of vegetation in positions of this kind is by deep penetration of roots to prevent movement of the ground below, and also by its matted growth at the surface to arrest crumbling and slip. Such vegetation by its sheltering effect will further prevent the ground from cracking in dry weather. The plants most suitable for the purpose are vigorous growers, with a tendency to "run" and form numerous offsets. Willows are good, especially *Salix pulchra*, and so is *Populus deltoidea*, on account of its deep-rooting capacity. In climates free from danger of severe frosts Tamarisks may be used with advantage, whilst species of Spiræa and the Snowball plant (*Symphoricarpus racemosus* and *vulgaris*) are recommended on account of their free "running" habit. In many situations the Red Valerian (*Centranthus ruber*) very rapidly covers the steep broken sur-

faces of cliffs, and as it occurs in three colours—pink, crimson, and white—it lends itself to attractive decorative effects.

As the study of vegetation in connection with the stabilizing and protection of cliffs and steeply-sloping ground is only in its infancy, there is no doubt that bold experiments among a wide selection of plants would lead to discoveries of great utility in the treatment of ground of this kind. Moreover, it has to be borne in mind that a plant which thrives in one exposure and climate will not necessarily adapt itself to other localities where these are different. Cliff gardening as a hobby has much to recommend it for its own sake as well.

The case just cited so fully is a good example of the value of sound diagnosis preceding treatment—a method which must always be followed to secure successful results. The wasting cliffs of soft incoherent material, clay and sand, such as those south of Cromer in Norfolk, the Bouldnor Cliff near Yarmouth, Isle of Wight, and the Bournemouth Cliffs, present certain outstanding problems. Primarily, no doubt, lack of protection at the base is the root of the evil, but given this, good judgment will be needed to heal the mobile face. The natural vegetation on these cliffs is by itself quite inadequate to hold the ground. The Cromer cliffs are infested by Coltsfoot (*Tussilago Farfara*), which develops everywhere its rhizomes, but these have no appreciable effect in stemming the flow of the viscous clay as it makes its way in sluggish cataracts to the foreshore. The same holds good of the Giant Horsetail (*Equisetum Telmateia*) on the Bouldnor Cliff. Ground like this needs drainage to eliminate the larger sources of water and planting with deep-rooting and spreading plants. Whilst there are many plants that should be tried, from want of knowledge we are only prepared definitely to recommend Willows and Poplars. When a department comes into existence to deal with coastal problems experimentally here is a matter that lies to its hands.

Analogous in many ways to the cliff face is the treatment of the slopes of railway cuttings and embankments where the materials have a tendency to slip—an effect due to the clay at a certain depth becoming saturated with water, so that the ground above slides down to a lower level under the influence

of gravity. Water gets access to the interior of the bank by means of cracks which develop during periods of drought, and the only remedy which engineers have discovered is the provision of very complete drainage for the removal of the water.

The expedient of planting various shrubs and trees has been tried, and though it may have mitigated the trouble it has hitherto failed to remove it. The problem to be solved is briefly the establishment on such places of trees or shrubs of deep-rooting habit, so that the layers of the bank may be bound together, and, in addition, the clothing of the surface with a continuous mat of low vegetation to screen it from desiccation and thus prevent cracking. Considering the very large number of plants available, it would be strange if foresters or skilled gardeners should be unable to find a satisfactory solution. Whilst it is easy to suggest the names of likely plants for the purpose, we are reluctant to do so in the absence of systematic trials. The trees employed, in addition to being deep rooters, will have to be fairly permeable to light to ensure a proper development of the ground vegetation. It will also be an advantage that the latter, when it dies off in autumn, should not too readily catch fire. These are the principal elements of the problem awaiting solution.

River Banks.—Creeks and river channels traversing saltings are very prone to erode their banks, especially in reaches which allow some "fetch" to the wind, which often springs up when the tide flows. To protect banks from the resulting "slog", simple expedients, such as stakes and boarding, rough bundles of brushwood, or better, properly made fascines, are commonly employed. Where the degree of salinity reaches the half strength of sea water (1.5 per cent of salt) trees cannot be used, as no tree-like halophyte is available outside the tropics.

Whatever the future may have in store, at the present time none of the mangrove trees of tropical mud flats has been acclimatized to serve the purpose, nor has any attempt been made to breed a form tolerant of a cool climate.

A few experiments have been made with Willows (*Salix alba*) to accustom them to salt water. Willow cuttings were attached to corks floating in fresh water, and as roots developed

the cuttings were transferred at intervals of a few days through a series of solutions of Tidman's sea salt, each solution being 0.1 per cent stronger than the last. The general result of this attempt to educate the willow to halophytic life was that all the cuttings survived the progressive shifts up to 1 per cent Tidman, whilst very few lived in 1.3 per cent, and none in 1.5 per cent.

Still, these results are sufficiently encouraging to deserve repetition with other species of willow; for undoubtedly it would be of great utility if a willow could be found to plant on the banks of tidal creeks.

At the top of an estuary the water at high tide rarely, if ever, reaches a high degree of salinity, and in such positions we are disposed to think willows might safely be planted; and even if the experiment turned out a failure not much harm would have been done.

As regards the caving of river banks in cases outside the influence of the sea, the following recommendations[1] are of value:—

"The willow is admirably adapted to holding alluvial soil in place. It is far more serviceable for this purpose than walls of masonry, and the facility with which it reproduces itself by seed, suckers, sprouts, and cuttings, both natural and artificial, makes its use very simple and inexpensive.

"The great difficulty with planting any sort of tree on perpendicular banks is that the caving of the soil is so rapid that the planted tree has no opportunity to get a start before it is undermined and precipitated into the river. An excellent scheme is as follows: Green willow poles, 18 to 20 feet long, are taken in spring and laid on the ground near the bank 2 feet apart, with their butts (ends pointed) directed towards the river. Woven fence wire is then stretched along over the poles and stapled fast to each one. Sections of wire about 100 feet long can be handled to best advantage. After the wire has been securely fastened to the poles, they are all pushed over the bank together, so that the pointed butts of the poles will fall and sink into the soft mud at the water's edge. As the bank caves off

[1] Taken from U.S. Department of Agriculture, Bureau of Forestry, Circular No. 27, by G. Pinchot.

some of the falling soil will lodge on the wire, partially burying and weighting down the poles, which will consequently strike root and grow. The wire will serve to hold the mass of willows together until they have become firmly rooted. The ends of the woven wire should be made fast to wire cables running back over the bank some distance, and fastened to posts set firmly in the ground. The caving and erosion of the bank will soon round off its top corners, and the growing willows at the water's edge will catch the soil as it rolls down the declivity, causing a bank to form of just the right slope to resist erosion most effectually."

Reclamation of River Sand and Shingle.—On the Continent of Europe the practice of recent years has tended to demonstrate the high value of the White Alder (*Alnus incana*) as a pioneer on all sorts of inhospitable and mobile soils. These include unstable mountain slopes, talus, river banks, and especially wastes of sand and shingle that cumber the beds of rivers liable to floods. Thus, on the River Ticino below Bellinzona, the Swiss have employed the White Alder with excellent results on the shifting shingly stretches of ground that border the actual channels.[1]

The method followed is to plant alder seedlings in their second year in double rows in shallow trenches running parallel to one another, and at right angles to the direction of stream flow. From these plantings parallel alder hedges, 6 to 9 feet apart, quickly arise, and acting as groynes they stabilize the ground and collect silt whereby the surface is appreciably raised. The roots spread into the spaces between the hedges, and in time the whole area is covered with a thicket of alders. A great merit of this plant is its habit of producing nitrogen-fixing tubercles on its roots, whereby the nutritive value of the soil is much increased. This type of planting requires about 5000 seedlings to the acre.

As the White Alder is quite hardy in Britain, and grows with great rapidity, it evidently deserves a full trial in connection with protective and reclamation work in this country.

In South Africa in the district of Oudtshoorn, in the Little

[1] See F. Aubert, *Schweizerische Zeitschrift für Forstwesen*, 1914, p. 207.

Shingly bed of Olifant's River, Cape Colony

Photos. supplied by Miss L. Britten

Groynes on Grobbelaar's River, Outshoorn, S. Africa

SHINGLE RECLAMATION

Karroo, where conditions more or less comparable to the Ticino obtain, the shingly wastes along the course of Grobbelaar's River are reclaimed by the construction of rough groynes built of water-worn boulders and pebbles, held together by coarse wire netting (Plate XXI). These groynes promote a raising of the level of the ground by silting, and the new land is taken over for ostrich farming, for which the district is famous. Lucerne is grown on the reclamations and fed to ostriches, in much the same way as sheep are folded.

The foregoing examples, which by no means exhaust the river-side problems capable of solution by simple expedients, must suffice for this part of our subject.

Apart from the fixation of sand dunes with its established routine, the employment of plants as agents in protection and reclamation work is still undeveloped, and it is premature to dogmatize on methods of treatment for particular cases. The whole subject needs further study and experimental exploration. But even when experience has accumulated it will be found that the special features of each case will require the most careful consideration, for the circumstances of soil, climate, and physical conditions are never identical in different cases.

CHAPTER XII

Blakeney Point, Norfolk, from an Engineering Point of View

It is proposed in this chapter to select a suitable demonstration area on the coast, and to describe its structure in relation to the dynamic phenomena which have determined and are still modifying its relief. The method pursued will be that of the guide-book, and the features recorded those with which the maritime engineer has concern.

Whilst there are many localities that would serve our purpose, we have decided on Blakeney Point, Norfolk, as our area, for two reasons. Firstly, Blakeney Point is comprehensive, including within reasonable compass the three great systems of the shore, namely, sand dunes, shingle beaches, and salt marshes. In this respect it is unrivalled.

The second reason for its selection is that Blakeney Point is a Nature Reserve under the National Trust, and hence will be available permanently for purposes of study.

As a consequence of these advantages the area is much resorted to by naturalists, whilst a convenient laboratory has recently sprung up, more particularly for investigations in maritime plant ecology.

Blakeney Point consists of a finger or spit of shingle some eight miles in length, which leaves the mainland near Weybourne on the coast road leading west from Sheringham to Wells. From the point of its departure the spit runs a trifle north of west almost parallel to the coast, and ends in the sea beyond Blakeney opposite the hamlet of Morston, from which the tip of the spit is distant about a mile and a half. The eastern part of the narrow area thus enclosed has been reclaimed

from tidal invasion by the construction of sea-walls, whilst the western part remains an open estuary, bordered by salt marshes and filling with the tide to form what is in effect an inland sea.

By far the best point for a general view is the top of the tower of Blakeney Church, which crowns the hill (itself more than 100 feet above sea-level), up which creeps the ancient, red-roofed seaport of much former prosperity. Beyond the shining muds, with their winding creeks and minor shipping towards the outlet, is the great shingle beach—a broad and toilsome causeway some 400 feet in width—and outside this the North Sea and no intervening land to the Pole. The spit of shingle is the outstanding topographical feature of this shore, and all else is subordinate to it. Under its lee an interrupted fringe of salt marshes has sprung up; whilst upon its surface, especially at its western end, blown sand from the shallow waters outside has drifted to form dunes. All this diversity of contour and relief, and much besides, is plainly visible from the church tower.

History relates nothing of the origin of the great beach, except that it has tended intermittently to push forward its non-attached western end. The result of the last hundred years seems to show that Blakeney Point has about reached the length of its tether; that whatever "records" it may have "broken" in the advance of its growing point in ancient times, there is little likelihood of its ever overlapping Stiffkey and Wells, as it has overlapped Cley, Blakeney, and Morston. Geologically, Blakeney Point has reached maturity. Shingle, obedient to the currents, still drifts along its seaward front from east to west, but these supplies for twenty years or more have tended rather to accumulate at and widen the distal end than to project it farther from its base. Quite lately new outer beaches have appeared overlapping the nose by several hundred yards; these in all probability will be driven inshore as were their predecessors of half a century ago.

The natural and convenient point of departure for a visit to Blakeney Point is the village of Cley, four miles by road from the railway station at Holt. It is natural, because Cley lies just at the point where the River Glaven discharges into tidal waters; Cley is, in effect, the head of the estuary. It is

convenient, because the traveller can choose the mode of approach—by foot along a sea-wall joining Cley to a point half-way along the beach, or by water to the western extremity itself.

Here we shall go out by water to the Point, and return on foot along the beach to Cley. In this the last-formed ground will be visited first, the older stages last. To do this a spring tide should be chosen. A start is made on the turn of the morning's tide. There will be water enough for the navigation

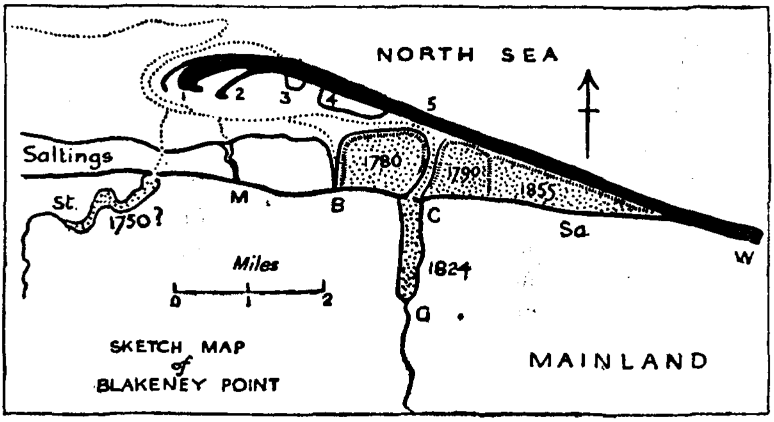


Fig. 49.—Sketch Map of Blakeney Point, showing the general features, the relation to the mainland, and the various reclaimed areas

1, The Headland; 2, the Long Hills; 3, the Hood; 4, the Marams; 5, Cley beach. Villages from west to east: St, Stiffkey; M, Morston; B, Blakeney; C, Cley; G, Glandford; Sa, Salthouse; W, Weybourne. The reclaimed areas are dotted, the dates of reclamation prior to 1824 being conjectural.

of the otherwise troublesome upper reaches, and the Point should be reached in not much over the hour.

Leaving the quayside hard by the windmill the Cley channel makes its way through a narrow, residual strip of high salt marsh to the beach, nearly a mile distant. On either side of the channel, at an average distance of 300 yards from one another, run two roughly parallel sea-walls. That to the east runs from Cley to the beach, and protects from tidal influence the Cley and Salthouse marshes (aggregating approximately 1000 acres). The bank on the west of Cley channel turns west 200 yards short of the beach, and circles round to Blakeney,

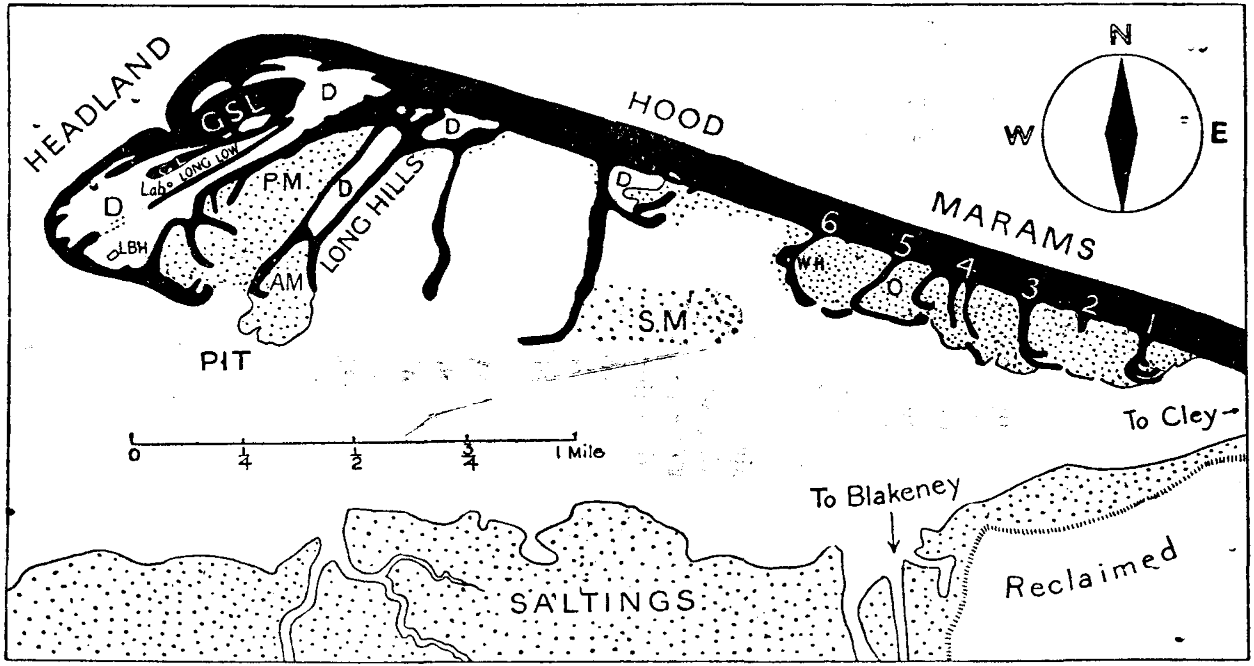


Fig. 50.—Map of Western End of Blakeney Point

Shingle is drawn black; salt marshes are dotted; dunes are marked D, but otherwise left plain. The new outer beach on the Headland is not mapped. References from left to right:—L.B.H., Life-boat House; Lab., Laboratory; G.L., Glaux Low; G.S.L., Great Sandy Low; P.M., the Salicornia-Pelvetia Marsh, known as Beachway; A.M., Aster Marsh; S.M., Samphire Marsh; W.H., Watch House on western hook of Marams; O, marsh on Marams covered with Obione; 1–6, hooks of Marams.

where the mainland is rejoined. It encloses 590 acres. Plate XXVII, 2, p. 240, gives a view of this bank looking in the direction of Cley. If to these areas be added the 240 acres lying to the south of Cley, and which constitute the original head of the Glaven estuary, banked in 1824, there results a total of some 1800 acres of land, nearly 3 square miles, reclaimed from the tidal waters of Blakeney Harbour.

The Cley channel on reaching the beach turns due west. Its right or northern bank for the next 600 to 700 yards is formed by the lee talus of the main shingle beach. This section of the beach being very mobile and bare of vegetation much shingle is liable to be thrown into the channel by such high spring tides as overflow the crest. Owing to these accumulations in the bed, navigation is impossible except to small boats at the spring tides; whilst a further consequence of these obstructions is the increasing difficulty found in draining (by gravitation) the Cley-Salthouse system of marshes, the outfall from which discharges into the Cley channel a quarter of a mile south of the beach.

Beyond this encumbered section the channel skirts a mile of high saltings fringing the beach and known as the "Marams"; at the western extremity of the Marams, on a high lateral shingle bank facing Blakeney, is the Watch House. (For details, cf. fig. 50.)

A third of a mile west of the Watch House is another excrescence of the main shingle beach, the Hood, a double-headed, Psamma-covered sand-hill, forming an excellent landmark; whilst in another three-quarters of a mile Pits Point, the southerly extremity of the Long Hills, is rounded, and the boat enters the section of channel known as the Pit, where such minor shipping as frequents the harbour rides at anchor at high water and rests on the mud at low. In former times the Pit is reported to have held as many as 140 vessels at one time, floating where they lay; now, by reason of silting, hardly a tenth of that number can find accommodation.[1]

[1] W. M. Cooke, miller, of Glandford Mill, in a letter to Joseph Hume, Tidal Harbours Commissioner, dated 3rd November, 1845, states that "Blakeney Harbour could once shelter 400 vessels; now our ablest pilots could not anchor 50 there" (Appendix to *Second Report of the Commissioners appointed to inquire into Tidal Harbours*, 1846, p. 472). Cooke, though not a seaman, was a close observer of tidal phenomena, as other passages in the Report show.

Landed on the shingle of the Headland, just south of the Life-boat House, the visitor finds himself in what may be termed the residential end of Blakeney Point. Dotted about within a small area are a few huts or bungalows privately owned, the old Life-boat House, which belongs to the Department of Botany at University College, London, and the Laboratory, a red-roofed building some little distance away. Standing between the flag-staff and the old Life-boat House is a dilapidated hut, the old Pilot House. Now surrounded by sand-hills and invisible from the sea, this house was erected on its present site about 1850, because at that time it commanded the best general view of the sea outside and of the approach of shipping to the harbour. The older seamen at Blakeney remember clearly a time when there were no sand-hills obstructing the view, whilst even in the last six years the advance of the dunes in this part is apparent to everybody familiar with the spot.

Blakeney Point, as a whole, from the point of departure at Weybourne to the Life-boat House at the western extremity, may be compared to a gigantic golf club, the head of which, deflected landwards, corresponds to the broad, dune-covered Headland. The line of telephone poles, which runs straight from the Life-boat House to the Bend of the beach, follows approximately the south-east fringe of the dunes where they abut on the great Salicornia marsh, which occupies the valley (or "Beach-way") between the Headland and the Long Hills, the latter being the long finger of shingle which ends at Pits Point.

Though at first sight the dune aggregate of the Headland may give the impression of being scattered without system, a stroll along the highest dune ridge parallel to the shore will suffice to show that the contrary is the case, and that the arrangement follows an orderly plan.

The foundations of the Headland consist of successive shingle beaches ("apposition beaches") with furrows or "lows" between. These beaches are approximately parallel to one another and to the major axis of the Headland (the line of telephone poles). These beaches have been driven in successively from the sea front, the outmost being the youngest, and they are formed of materials that have drifted along the fore-

shore from farther east. The effective outside beach of the moment (which projects well beyond the Headland) appeared as recently as 1912, and when it has been pushed inshore a certain distance it is to be expected that a still younger beach will take its place.

The crests of these beaches become dotted about with plants soon after they appear, and such of these plants (especially Psamma) as have the power of arresting sand blown in from the shore at low tide become the starting-points of sand dunes. The plants settle by preference on the crest because their seeds are brought by the sea in the drift, and it is a characteristic of drift lines to reach the level of the highest tide of the cycle.

Thus it has come about that the dunes form five or six successive ranges parallel to the shore. Each range as it arises tends to screen the preceding one from the source of blowing sand, consequently it is found under these conditions that vertical growth slows down till it becomes stationary. Later, unless the dunes become entirely covered with a turf of vegetation, they shrink gradually as sand is blown from their summits.

All stages in dune development and destruction can be studied on the Headland. First, the isolated tufts of plants which collect little heaps of sand; next, the blending of these into systems as the level rises and the grass spreads. At this stage vertical growth has been found to average about one foot a year. The highest ranges do not exceed 25 feet above mean sea-level. Farther back the dunes are lower and are closely turfed over, especially by mosses and in some places by lichens. Owing to the large population of rabbits on the Headland bare sand is being continually exposed to the wind, and the disappearance of the older dunes is only a question of time, unless the rabbits are exterminated or effective shelter be given by the planting of trees. Excellent examples of disappearing dunes are to be found as the Bend is approached along the line of telephone poles, where an extensive area of bare shingle (the "desert") has been exposed. However, "Nature abhors a vacuum", and with the lowering of the ground to tidal level the higher spring tides get access, and, bringing drift and seeds

Photo. W. Rowan

Glaux Low, looking N.E.

Lows in Dune System of Headland filled by a high tide

BLAKENEY POINT

(especially of *Statice binervosa*), this stony desert clothes itself in August with sheets of purple visible from afar.

The lows separating the dune ranges differ from ordinary valleys in that they have never been excavated from a previously continuous terrain. They are gaps left from the first in the system of construction. The best example is Long Low, running from the Life-boat House to the north-west of the huts and to the south-east of the Laboratory. It dies out towards the Bend some three-quarters of a mile from its point of origin. Two hundred yards north-east of the Laboratory it is blocked by a bridge of sand blown from an adjacent dune. Glaux Low lies just north-west of the Laboratory, and can be followed for a distance of nearly half a mile in a north-east direction, where it communicates with Long Low (Plate XXII, lower picture). In the direction of the Life-boat House it has been long practically obliterated by blown sand, excepting the south-west extremity which is still open. Seaward of Glaux Low is Great Sandy Low, the dominating feature of the topography on the outside of the Headland (Pl. IV, 2, p. 58). This low is essentially a long bay of some ten acres penetrating the heart of the dunes. Into Great Sandy Low the spring tides flow, and the very highest (not more than one or two a year) reach the north-east parts of Glaux and Long Lows. Owing to sand blockages the south-west parts of these lows are inaccessible except on the rarest occasions. Thus, the end of Glaux Low by the Laboratory has been reached by the tide only twice in the years 1913-6, whilst Long Low, from the sand block to the Life-boat House, was invaded by the tide on 14th September, 1916, for the first time since November, 1897. From an engineering point of view these lows are of considerable interest, because they afford lines of access for the sea. Theoretically, each low should be an isolated valley, but as a matter of fact the sea has established points of connection between them, as a study of the ground or of the map (fig. 50, p. 221) will show. As the floor of the low is commonly appreciably below the level of the point of entrance by the sea, the tide pours in with a tremendous rush, undercutting the sides and lowering the floor. In this way every tide makes it easier for the next one to gain access, and in the

long run the whole stability of the Headland must be impaired (Plate XXII, lower picture, shows lows in the interior of the Headland dunes filled by a high tide).

The remedy is fairly obvious, though in practice not always immediately successful. On several occasions the strategic points of communication between these lows have been blocked with stout brushwood fences, in the hope that wind-borne sand might accumulate in the form of artificial dunes massive enough to resist the impact of these high spring tides. On each occasion, however, a high tide came many months earlier than was expected, and before the dunes had been fully built up and consolidated by Psamma. The tides here are very sensitive to windage, and a gale from the north or north-west will raise the level of high water several feet above the prediction of the tide-table.

A feature of no little interest is the fact that fresh water can generally be obtained by digging wells in these shingle lows. In Long Low near the Life-boat House a row of four such wells was dug in July, 1914, and they have continued to yield an inexhaustible supply of good potable water since that date. The level of the water in these wells rises and falls with the tidal cycles, showing a lag of about three days. That is to say, three days after the highest spring tide the wells attain their highest, and three days after the lowest neap their lowest level, the oscillation in the wells being from 15 to 20 inches. It is evident that the fresh water is floating on the salt, and it is remarkable that it should not undergo appreciable contamination.

Shingle beaches above tide marks are in general drenched with fresh water, and so far as our experience goes show no abatement even in seasons of prolonged drought such as the summer of 1911. It may be conjectured that shingle has the property of condensing dew internally, a property perhaps shared by the sand dune as well.[1]

To the botanist the colonization of shingle lows is not without interest. The older sorts bear little save a sparing turf of the little *Plantago Coronopus* v. *pygmæa*. Under moister conditions, *Glaux maritima* (as in Glaux Low) appears, and

[1] *New Phytologist*, Vol. XI, p. 98; *Journal of Ecology*, Vol. II, p. 35.

THE BEACHWAY, BLAKENEY POINT, LOOKING N.E.

On the left are the dunes of the Headland; from the edge of these, low shingle laterals run out into the Salicornia Marsh, bearing bushes of *Suæda fruticosa* close cropped by rabbits. On the right are the Long Hills and the waters of the Estuary

may even spread to form a continuous covering. The establishment of additional species will depend on the opportunities that occur for the bringing of seed, and whether the sea has regular access. In the latter case it is likely that the low will develop into a salt marsh.

Before leaving the dunes of the Headland a general view of the large Salicornia marsh should be obtained, preferably from the sand-hill south-east of the Laboratory on which the fifth telephone pole from the Boat House stands. This point commands the whole expanse of this marsh, some 60 or 70 acres in extent, occupying the flat ground between the dunes of the Headland and the Long Hills Bank. In summer it consists of a green carpet of *Salicornia annua*, with which is associated the unrooted and sterile *libera* form of the brown seaweed *Pelvetia canaliculata*. Covered by nearly all the spring tides this marsh represents an early stage in the development of a salting. Observations show that the level of the Salicornia marsh is rising yearly from one-half to three-fifths of an inch in its middle parts.

On its north-west side the marsh is divided into bays or compartments by four or five low shingle beaches, conspicuous objects from the view-point (Plate XXIII). These beaches in the history of the development of the Point must formerly, each in turn, have represented the organic apex of the whole system. Successively they were deflected into their present positions before the main platform of the Headland had been formed, and as each hook was overtopped by the next one formed it would be screened from direct impact of waves and pass into the dormant state. The long hook which closes in the Salicornia marsh, separating it from the main estuary, and which runs from the Life-boat House to beyond the house-boat *Britannia*, is still mobile. Evidence of its recent marshward travel is afforded by the stools of Suæda bushes still persisting some yards outside it; originally these bushes grew on the inner fringe of the beach, which has passed completely over them.

The hooks which project into the Salicornia marsh are typical of the whole system of construction of Blakeney Point from the Marams to the Life-boat House. The accompanying

diagram (fig. 51) shows these lateral beaches numbered in the order of their sequence. They occur in three groups, forming the Marams, the Hood, and the Long Hills and Headland. *In length, individual hooks range from a few hundred feet to* half a mile, whilst the nature of the vegetation they bear varies according to the age of the hook, or what is the same thing, its position in the system as a whole. Ancient hooks, such as those of the Marams, have acquired by lapse of time a surface soil bearing a turfy carpet of grass; those most recently produced bear little besides that most ubiquitous of the Blakeney

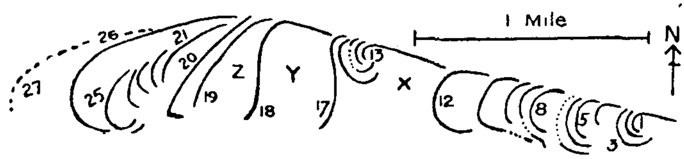


Fig. 51.—Diagram of the Shingle Systems of the Distal Three Miles of Blakeney Point, to show the separate banks and their order of origin

The series 1 to 12 with the enclosed marshes form an aggregate known as the Marams; Nos. 13 to 17 are covered in large part by a sand-hill termed the Hood; the Long Hills overlie Nos. 19 and 20, and the Headland occupies the area within No. 26. Between these two sets of sand dunes is the Salicornia marsh. The last-formed beach (No. 27) is dotted. All the marshes belong to the narrow-mouthed type with the exception of *x*, *y*, and *z*, which are of the open variety.

shingle plants, *Suæda fruticosa*. Between these extremes the Long Hills bank of intermediate age may serve as an example of a transitional vegetation.

Leaving the sand-hill which has served as view-point, we may proceed along the edge of the marsh about half-way to the Bend. Walking over the low shingle hooks, it will be noticed that the Suæda bushes are dwarf and stunted, and, if it is several days since a tide flowed into the marsh, twigs of Suæda will be found lying about. This destruction is caused by rabbits, which throughout the season never relax the habit of pruning the Suæda. In the aggregate, the result of this constant rabbit pressure is tremendous, as the drift line testifies. An adequate explanation of this Suæda habit has yet to be found. The rabbits do not eat the twigs, which remain lying about till the tide sweeps them up. It is possible that the rabbits sharpen their teeth this way, or the taste may be pleasant; on the other hand it may be merely a mischievous

Aster Tripolium nibbled by rabbits; *Salicornia annua* and Pelvetia also present

Photos. W. Rowan

Rabbit runs on Salicornia Marsh

RABBIT PHENOMENA (BLAKENEY POINT)

habit. *Suæda fruticosa* also grows in quantity on the Chesil Bank in Dorset, and here it is bitten by hares, which travel miles for the purpose. The hare with its greater strength is able to gnaw through quite thick branches, and does not restrict itself to small twigs like the Blakeney rabbits.

The Sea Purslane (*Obione*) suffers in just the same way, and in some places is mowed down by the rabbits to form a beautiful lawn. It is interesting to note that in colour the rabbit-cropped Suædas are most variable, ranging through green to dull-red and crimson. Suædas, when untouched by rabbits, as on the Marams, show a slight tendency in autumn to assume these various shades, but it is only where they are habitually nibbled that a vivid colour mosaic is a constant feature. The inner cause of the phenomenon has not been investigated.

Crossing the marsh some distance to the north of an old steam lighter fitted up as a house-boat (*Yankee*), and moored alongside the Long Hills bank, the composition and texture of the vegetation can be examined. The marginal zone of the marsh contrasts with the main area in the presence of Obione, *Salicornia radicans* (a perennial species), and *Suæda maritima*, and in the absence of Pelvetia. *Salicornia annua*, which with Pelvetia forms the substance of the marsh, is here only scattered and dwarfed. On the main area the Salicornia owes not a little to the Pelvetia, which nurses it in the seedling stage, and as a mulch prevents drying of the surface during the neaps. By its disintegration much humus is added to the soil and high fertility maintained.

At many places rabbit runs crossing the Salicornia are evident (Plate XXIV, lower figure). If followed, they will generally be found to lead across the minor creeks at points where they are narrow, and the footprints left by the rabbits in jumping and alighting are discoverable in the soft mud of the bank. These runs lead to the Sea Asters (now becoming everywhere abundant), upon which the rabbits feed eagerly, and it is rare to find on this marsh an aster quite free from the attentions of these animals (Plate XXIV, upper photo), except in the fenced enclosure hereabouts, which serves to emphasize the effect of rabbit browsing.

Arrived on the Long Hills, it will be noted that the covering of dunes is more mature than anywhere on the Headland itself. More species of plants have settled in, and the lichens (Cladonias) are relatively much more important in covering the ground. There are also numerous fine clumps of the polypody fern—not to be seen elsewhere on the Point.

The main object of the visit to the Long Hills is to examine the southern extremity of the bank. Prior to 1911 the end ran straight out, but during the winter of 1911–12 continued tempests from the west destroyed the tip, and re-arranged the shingle as a hook pointing east. This hook is now nearly 200 feet long, and curved like a jetty (Plate XXV, lower photo). Its sudden apparition has disorganized considerably the tidal irrigation of part of the marsh to the east of the Long Hills bank, but its chief interest lies in the fact that its formation explains how the similar curved type of hooks on the Marams arose. These can be inspected on the way back to Cley.

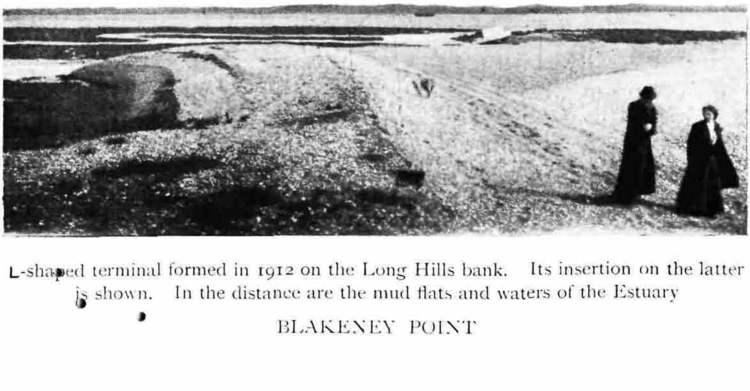
The bushes of *Suæda fruticosa*, now present on the crest of this new bank at its point of insertion, have been derived directly from Suædas which flourished on the eastern slope of the old bank before the catastrophe. These, when overwhelmed, grew up through the new shingle and took root at the higher level. It is this characteristic, combined with great robustness of habit, that makes *Suæda fruticosa* potentially one of the most valuable of all maritime plants for purposes of coastal defence, ranking indeed with Psamma itself.

The return journey to Cley will be made on foot. Leaving the Long Hills just beyond the house-boat *Yankee*, a line may be taken direct to the Hood across the sands, or if they are too sloppy, the fringe to the main beach may be followed.

The flats on this side of the Long Hills are still for the most part bare of higher plants, except for a thin scattering of *Salicornia annua*, now rapidly spreading. The higher parts between the neap and spring high-water marks on the Long Hills side show very typical development of the blue-green alga Microcoleus, an important accretor of mud. It can be recognized by a tendency shown by the surface layers to flake off during the periods of the neaps in summer. If a specimen be examined

Photo. E. P. Farrow

A Samphire Gatherer; the Hood seen on the sky-line



L-shaped terminal formed in 1912 on the Long Hills bank. Its insertion on the latter is shown. In the distance are the mud flats and waters of the Estuary

in water, it will be found to consist of the matted algal filaments, with soil held in the interstices; and if it be kept moist under a bell-glass, the filaments will emerge like a blue-green velvet on the surface.

The Hood is a crater-shaped sand-hill covered with Psamma, *Carex arenaria*, and in places with the glaucous, tufted, and rather rigid *Corynephorus canescens*—this last a characteristic East Anglian seaside grass. The general flora of the Hood is richer than that of either the Long Hills or Headland, in consequence, doubtless, of its greater age. In the summer of 1910 it was accidentally burnt over, but the grasses quickly recovered, and no ill effects supervened.

The Hood stands on a complex of dormant shingle hooks, parts of some of which are exposed on the eastern side. The surface pebbles on their crests show a rich covering of lichens, *Buellia colludens* (black) and *Physcia parietina* (orange) being the principal species. In the centre of the Hood is a little bay reached by the highest spring tides, and in this a tiny *Juncus maritimus* marsh—the only example on Blakeney Point itself.

Lying due south of the Hood, and about a quarter of a mile distant in the centre of the Horn Sands, is a newly-developed marsh known as the Samphire Marsh, for it is here especially that the people from the mainland come to collect the Marsh Samphire (Salicornia) for pickling (Plate XXV, upper picture).

Up to 1910 this marsh bore only a sprinkling of Salicornias and a few Asters, but during the last few years it has advanced very rapidly indeed, the Salicornias now forming a dense carpet, whilst the Asters are all over the place. Two species of annual Salicornia are present, *S. annua* and *S. dolichostachya*. At the earlier date the latter was the more abundant, and this is the species which the Samphire gatherers especially collected. It is distinguished by its long tapering flowering spikes. In 1916, *S. dolichostachya* had become relatively less abundant, but it would be premature to say that this is the direct result of overpicking, although in view of the plant being an annual the explanation is plausible. It is possible, of course, that this species flourishes best in the early stages of colonization, and

that the dwindling noted is a normal preparation for the next succession.

The marsh is worth inspection, if only to see *Fucus limicola* in its prime. It may be remembered (see p. 172) that this sea-weed becomes bedded in the mud, and is most active in promoting accretion. The vertical growth of this marsh (which is just covered by the neap tides) was found to be approximately 1½ inches per annum in 1914 and 1915, whilst the high loss on ignition (8.4 per cent of the dry weight) points to a considerable richness of the soil in humus.

Pari passu with the advance of the Samphire Marsh, and doubtless causally related with it, is the colonization of the ground between the Hood and the western bank of the Marams, on which the Watch House stands. Up to 1910 Salicornia was present in moderate amount at the corners where the Hood and Watch House banks, respectively, join the main shingle beach. Since that date the plant has spread much as on the Samphire Marsh, so that now (1917) a broad continuous belt of green here runs parallel to the beach.

Only a few years ago this portion of the Blakeney area was notorious for its soft and treacherous mud, the character of which will be appreciated when it is explained that it was considered a good joke on some pretext to get an unsuspicious stranger to attempt to cross the slough.

The Main Beach from the Long Hills to the Watch House.—This portion of the beach, though exceptionally rich in Sea Poppy (*Glaucium luteum*), is, on the whole, relatively poor in the more persistent beach plants, such as *Suæda fruticosa*, *Silene maritima*, and *Arenaria peploides* (Plate X, 1, p. 98). It is divided by the Hood into two sections, very similar in nature and of approximately equal length. Both sections are exposed to the open harbour on the lee (south) side, and when the wind blows from the direction of Morston and Stiffkey, i.e. from the south-west, the waves at high tide disturb the shingle a good deal, and make it difficult for *Suæda fruticosa* to establish on the fringe. This probably accounts for the almost entire absence of this plant from the middle portions of the two open embayments west and east of the Hood. However, since the Samphire

Marsh off the Hood began to rise in level, the section from the Hood to the Watch House has enjoyed some slight measure of protection, and this finds expression in the establishment of a line of Suæda seedlings from the Hood for a distance of several hundred yards in the direction of the Watch House. These seedlings arose from seed ripened in 1912 and left all along the drift line. Originally the line was continuous, but by the summer of 1916 there were a good many gaps. By that time the average height of the survivors, sturdy little plants, was about 18 inches.

Should the Samphire Marsh continue to rise, it is to be expected that Suæda seedlings will eventually spread all along this section of bank.

Another feature of interest on both these sections is the eastward drift of the shingle along the lee fringe. This results from the south-westerly gales. As a consequence, the shingle tends to accumulate in the western corners of the Hood and Watch House bank, respectively.

The accumulation by the Watch House is very striking indeed, forming a marked excrescence which has sensibly increased during the last six years. Should it continue, the head of the angle or recess will be isolated as a "low" when the bulge stretches across to meet the Watch House bank. These corners are also regular traps for vegetable drift (seaweed and Zostera), which is swept up here in quantities from the muds of the harbour. As a consequence, a rich humus soil is formed in which the Suæda bushes luxuriate.

The shingle which accumulates to form the bulge represents attrition from the lee face of the bank; it is not replaced by drift from farther west, as the Hood stands in the way, and acts as a natural groyne. The only source from which it can be replaced is by shingle washed down from the crest by super-tides; whether this in amount compensates for the wastage it is impossible, to say.

This same section of beach exhibits occasionally, in common with the stretch between the Marams and Cley, another phenomenon, viz. percolation ravines. With very high tides the whole top of the beach is gorged with sea water, and at the ebb much

of this water discharges on the lee side, carving out ravines every few yards, and shooting out the shingle displaced in the form of talus fans on the foreshore. After the high tide of 14th September, 1916, scores of these ravines appeared, resembling in all respects except size those of the Chesil Beach. The ravines were developed on the steep lee slope, reaching up about 6 feet from ordinary high-water mark, 2 to 3 feet deep, and 3 to 4 feet wide. A man lying down could get excellent cover in one of these ravines; and, indeed, it might have been supposed that soldiers had been practising some new system of entrenchment. The next high tide was some 2 feet lower than the tops of the ravines, and its effect was to obliterate their lower two-thirds by lateral shingle drift. The upper limb of each ravine, being above the influence of this tide, persisted as an oval hole about the size of a clothes basket. Had one not seen the ravines freshly made, the "clothes baskets" must have been quite unintelligible.

The Marams.—The stretch of beach, a mile long, extending east from the Watch House to Cley beach, is perhaps the most interesting part of the area from an engineering point of view. It is known as the "Marams", though no blown sand enters into its construction. As, however, a few tufts of Marram Grass occur here and there on this section of the main beach, it is quite possible that the name is really significant of the presence here at some remote period of Psamma-covered sand dunes.

The great features of this section of the beach are:—

(1) The numerous hooks which it bears along the lee side;
(2) The advanced phases of marsh building shown by the land between the hooks; and
(3) The mobility of the main beach in relation to the distribution of the vegetation, more particularly the Suæda bushes.

The Hooks, which are six in number, are some of them simple and some compound, the latter consisting each of two or three hooks in lateral contact. The relief of the ground makes it possible clearly to distinguish the real nature of these

compound hooks, whilst the interstices are commonly wider at the distal than at the proximal ends. The hook on which the Watch House stands, and the one immediately to the east of it, are good examples of simple hooks; most of the others are compound.

The terminals of the hooks are all of them bent round at a right angle, so that they lie east and west. Probably this adjustment has been caused by ancient storms from the west or south-west, just as recently the tip of the Long Hills bank was turned through a right angle in the course of a single winter (cf. p. 230). The result is that the marshes between the hooks are narrow-mouthed, and sheltered from wave action on the south, a condition that must have promoted their colonization by halophytes and a rapid raising of their level by deposition of silt.

The hooks of the Marams stand much higher than those which project into the Salicornia marsh of the Headland, and are not covered by any of the spring tides. Except for their ends, which are exposed to some extent to scour from the waters of the harbour, the shingle of the hooks has become stabilized, and carries a continuous vegetation. This vegetation is zoned, the principal zones from below upwards being characterized by *Suæda fruticosa*, *Festuca rubra*, *Statice binervosa*, and the vegetation of the crest. The Suæda of the hooks is continuous with that of the marginal belt of the main beach; its growth, however, is less vigorous on account of the dormancy of the ground.

The marsh units of the Marams are the bays between the hooks, each irrigated and drained by its own creek. The height of these marshes is such that they are overrun by the higher spring tides only. Accretion, though still in progress, hardly exceeds ¼ inch per annum.

The westernmost marsh of the series, adjacent to the Watch House bank, is a typical "mixed salting", bearing most of the commoner perennial halophytes. Its margin, however, has already been invaded by the Sea Purslane (*Obione portulacoides*), which plant has become dominant over most of the other marshes of the series (Plate XVI, p. 176, lower). The occurrence of this

invader everywhere has prevented the marshes entering on their normal terminal succession, wherein broad swards of *Glyceria maritima* should be the conspicuous element. To find this type we have to look at the higher saltings on the south side of the estuary, outside the diked marshes between Blakeney and Cley.

That the marshes of the Marams in their earlier phases resembled the Salicornia marsh of the Headland seems probable. Thus, at many spots, surviving vestiges may still be found of the old Pelvetia-Salicornia community.

In spite of these various accessory structures, it is the main beach which offers the principal interest in this Marams section. This part of the main beach is mobile throughout, and yet its mobility is restrained by the numerous hooks which act as stabilizing cores, over which it must necessarily progress in its landward travel. This retardation tends to make the Marams section a salient, whilst the close proximity of so considerable an area of marshes provides the lee fringe with a constant supply of vegetable drift. These factors together favour the establishment of a fairly rich vegetation, and this in its turn co-operates towards the same result. That is to say, the hooks and the vegetation promoted by the natural manuring by drift act reciprocally in slowing down the travel of this part of the beach.

The details of the relation of the distribution of the Suæda bushes to the relief of the beach can be studied under the most favourable conditions along this section—more particularly from a point half a mile east of the Watch House to the east end of the Marams.

Fans of talus brought down from the crest to the lee edge project over the marshes at frequent intervals (cf. fig. 28, p. 109), and it will be found in each case that these fans are fed by definite gullies which cross the beach at right angles—passing through gaps in the rows or zones of bushes (Plate XXVI). In several cases recent talus will be found capping older talus on these fans, thus showing that the gullies are permanent lines of transport which function intermittently according to the incidence of the super-tides which top the crest.

LANDWARD SIDE OF BLAKENEY MAIN BEACH (MAKAMS SECTION)

With talus fans, the three Suæda zones, and the dynamic lines. The more conspicuous plants other than *Suæda fruticosa* are *Silene maritima*, *Rumex trigranulatus*, *Arenaria peploides*, and *Festuca rubra*

Along the eastern half of the Marams the Suæda bushes run in three distinct zones (Plate XXVI):—

(1) A marginal zone along the lee fringe of the beach;
(2) An intermediate zone; and
(3) An upper zone.

The marginal zone is the one most recently established; it is continually increasing by invasion. It probably dates from 1897, the year of the last very great tidal inundation. Prior to that year the present intermediate zone probably occupied the marginal position, whilst the upper zone dates back to a much earlier period. On this view the two bare intervals of shingle between the zones of bushes correspond to advances of the shingle—the lower one to the tide of 1897, the upper to some previous unascertained date. The general relations of the Suæda bushes to beach travel have already been fully illustrated and described at pp. 106–110.

It has frequently been stated that the lee fringe is the region of establishment of Suæda bushes, and this is probably true as to 99 per cent of such cases. Occasional seedlings, however, can and do germinate and establish in other positions—even on the crest itself. Between the Watch House and the end of the road from Cley (a distance of 1¾ miles) fifty such seedlings have been detected, and there is little doubt this number would be indefinitely increased did natural processes continually operate in distributing broadcast the seed and the drift.

The Cley Beach Section.—Continuing east from the Marams the beach becomes bare and very mobile, the crest is uneven and liable to be overrun by the highest tides. Whenever big seas and big tides come together it is Cley Beach that suffers first, and much shingle is transported to the lee fringe, where it is shot into the channel. It is within the memory of by no means the oldest inhabitants that there was formerly a considerable strip of saltings between the beach and the channel—perhaps 50 feet wide. This has long disappeared through the landward travel of the beach, and now every ton of shingle washed over finds its way direct into the bed of the channel,

so that the discharge of the tidal water is retarded and navigation impeded.

Proposals have recently been made to dig a new channel through the saltings some distance to the south of the existing one, an expedient which has much to recommend it. At the same time, for such an enterprise to have lasting value it would be necessary to plant up the beach itself; otherwise the new channel would be overtaken in a few years and the present position reproduced.

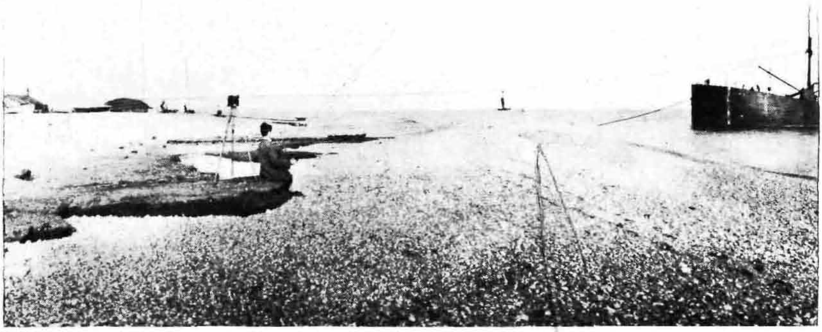
The principal features in the relief of this section of beach are the gullies along which shingle is transported and the percolation ravines. Talus fans occur at the ends of the gullies after a big tide, but do not persist, as the scour of the channel soon distributes the shingle along the bed.

At the point where the telephone poles turn landwards is the causeway to Cley, which is distant a mile from the beach. Just west of this point the channel turns south and runs between saltings to the same destination. Actually, the causeway lies east of the bank, which protects from the tide the marshes between Cley and Salthouse.

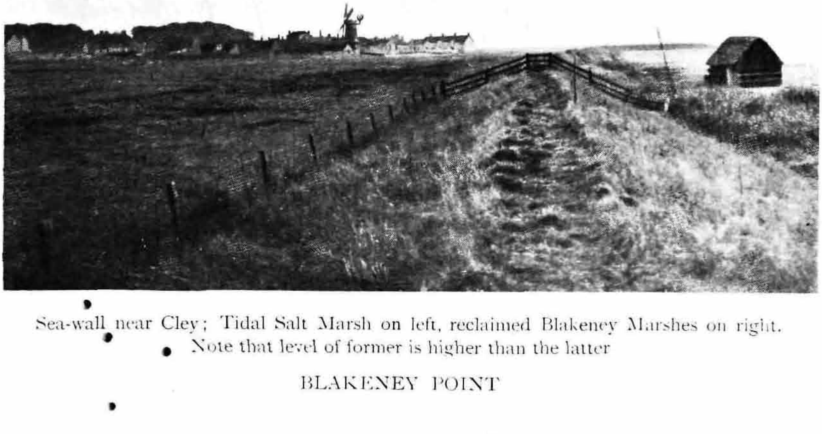
Except for wheeled traffic the usual road is along the flat top of the dike, and this is to be recommended for its extended view. The mainland from Stiffkey to Sheringham is visible; the Harbour from the Life-boat House in the west to the reclaimed marshes beyond Salthouse; whilst the land about the ancient head of the estuary, which ran below Wiveton Church up to Glandford, lies beyond Cley windmill, which stands near where the bank joins the mainland.

It will be noticed that the tidal saltings are some two feet higher than the reclaimed marshes within the bank. This difference is due in part to a slight settlement undergone by the latter after isolation, but chiefly to the continued accretion of the saltings, which are, of course, covered by all the higher spring tides. (Cf. Plate XXVII, lower photograph.)

In Cley village many traces still remain of former maritime activity. The channel by the old staithe has shrunk away almost to nothing, but the old Custom-house remains; whilst facing the George Hotel is the end of what was a long row



Cley Beach, showing outcrop of floor of Salt Marsh (seated figure) over which the beach has travelled. On right wrecked S.S. *Vera*, beached after collision with a mine-sweeper



Sea-wall near Cley; Tidal Salt Marsh on left, reclaimed Blakeney Marshes on right. Note that level of former is higher than the latter

BLAKENEY POINT

of granaries, now converted into cottage tenements and a Village Institute.

Cley to Weybourne.—The sea frontage east of Cley Beach and the marshes behind are well worth inspection by the engineer, on account of the inroads which the sea has made into works ambitiously conceived but inadequately maintained. A visit is most conveniently made by following the coast road east from Cley to Salthouse, and then crossing the marshes by the road which leads to the Rocket House opposite Salthouse. The round is completed by returning to Cley via Cley Beach.

On leaving Cley by the Sheringham road the south end of the east bank (with stile) is passed just beyond the last house on the left, and a few yards farther on the causeway (gate) leading to Cley Beach. The road now skirts the reclaimed marshes (Cley Marshes). Five furlongs farther on a bank parallel to the last leaves the road; these two banks and a connecting wall on the front parallel to the beach protect the Cley system of reclaimed marshes. This intake dates from 1790. For a period of fifty years from this date it was possible for a boat to sail at high tide from the Cley channel at the bend between the main beach and the bank; access was thus gained to Salthouse Broad, which lay to the east of the Cley Marshes. About 1845 this entrance was closed by the advance of the beach (cf. fig. 49, p. 220).

Some 500 yards east of the second bank, at a point one mile from Cley, the steep bank or bluff to the south of the road should be ascended. From this point a wide prospect of marshes is obtained closed in to the north by the Salthouse sea-wall, built in 1851 at a cost of £10,000, to exclude the sea from the Salthouse Marshes (including Salthouse Broad). This wall, as will be seen, has been broken at numerous points and has never been repaired.

The view-point itself has also an interest. The soil and the plants thereon proclaim it an ancient sand dune. This means that long ago, before either the marshes or the shingle beach existed, the open sea washed the foot of this bluff, and brought the sand which was blown by the wind into its present position.

Continuing along the road, past the "Dun Cow", the windmill and village of Salthouse, a causeway leads across the marshes to the conspicuous Rocket House. All along this front to the corner of the Cley Marshes are the remains of the sea-wall of 1851. This wall, 2 miles in length, has been overtaken by the beach, which now lies piled up against it for a large part of the distance, and at many points is level with the top of what remains, and running over.

The sea-wall is breached at numerous points, and no section over 100 yards in length remains intact. The gaps in the wall have been produced by the sea washing over the crest and eroding the mud, whilst at some spots when the marshes were in flood the wall has been undercut by scour from the south side.

With the deepening of the gaps the sea began to wash the shingle through, spreading it out in the form of circular detrital fans standing about 2 feet above the marsh level.

Thus, 100 yards east of the Rocket House, a 20-foot gap has admitted a level detrital fan 100 feet across (north to south) and 100 feet wide (east to west). The height is approximately 2 feet.[1]

Opposite the "Dun Cow" at Salthouse there is a very broad breach with fan to correspond. In 1913 the surface of the latter was beginning to be colonized by Horned Poppy and Dock. About 400 yards farther west, opposite a pair of drains crossing the marsh, a breach was just beginning, and pebbles were already drifting over the gap. At one place a number of breaches occur close together, and much shingle has drifted through them. The lines of flow are marked by gullies like those in percolation ravines, whilst shingle is deflected and accumulates under the lee of the surviving wall fragments, reaching a height of perhaps 4 feet, and recalling the relation that obtains between a Psamma tuft and the "tail" of sand that accumulates under its protection. In the case of the Psamma the agent of transport is wind, whilst the shingle, of course, is carried along by water.

The areas of marsh covered by these detrital fans, are lost for grazing, whilst the gaps have to be fenced to prevent cattle straying on to the beach.

[1] These dimensions were noted in March, 1913. The damage may have increased since that date.

The general consequences of the neglect of the Salthouse wall are:—

(1) The frequent flooding of the marshes, which renders an appreciable proportion of the total area unproductive.
(2) Increasing areas of the marshes destroyed by the intrusion of shingle.
(3) Choking of the drains with flood water, thus aggravating the congestion in the obstructed Cley channel where the main drain discharges.

The phenomena presented in the course of a walk along this front are decidedly instructive, and will thoroughly repay the trouble.

The Cley Marshes present a different problem. The wall has never been allowed to fall into disrepair, but trouble has arisen because the north-eastern corner has developed into a salient owing to the advance of the beach. This salient is projecting more and more out to sea, and the wall (concrete) is liable to damage from storms, entailing great expense in upkeep. It is probable that the position will in time become untenable, and that the wall will have to be set back and the salient abandoned.

Along this part of the beach, about the high-water mark of the neap tides, the old marsh floor can often be detected on the sea front (Plate XXVII, upper photo). The beach has passed right over it, and fragments of peaty material containing residues of plants break away as the layer is eroded by the waves. The same thing may be found at other points between Salthouse and the Marams Watch House, when the shingle on the face has been temporarily washed down to a lower level.

Cley can be regained by continuing west along the sea-wall to the causeway on Cley Beach, or the bank between the Cley and Salthouse marshes can be followed to the Sheringham road.

CHAPTER XIII

The State and Local Control

A vast literature has been evolved on every aspect of the question of coast erosion. In 1906 a Royal Commission was appointed, and their third and final report was not issued until five years later. The subject was investigated by them in an exhaustive manner, the commissioners visiting the coast-lines of England, Scotland, Ireland, Holland, and Belgium in the course of their enquiry. The references to the Royal Commission included:—

(*a*) Facts relating to the encroachment of the sea; damage caused or likely to be caused thereby; recommendations as to preventive measures.

(*b*) The advisability of conferring further powers on local authorities and landowners, with regard to securing more effective administration in the work of protecting the open coast and the banks of tidal rivers.

(*c*) The legal situation with regard to the management and control of foreshores; recommendations as to modifications in existing law.

(*d*) Facilities, if any, which should be given for the reclamation of tidal lands.

The final report dealt with the subject in the following aspects:—

(1) Topographical and geological considerations.

(2) The extent of erosion as compared with accretion and artificial reclamation.

(3) On the technical evidence given before them.

(4) Regulations relating to central and local administration.

(5) The reclamation of tidal lands, and the use of unemployed labour in effecting such reclamation.
(6) The alleged obligation of the Crown to defend all foreshores.

The contention that inroads of the sea are to be regarded in the same light as the invasion of a foreign power, and that, therefore, it is equally the function of the State to take preventive measures in the two cases, is doubtless theoretically sound, but the difficulty presents itself that there are no means of enforcing decisions. The Crown claims ownership of the strand between high- and low-water levels, and legal decisions confirm this view. Inversely, however, the Crown is not answerable to the jurisdiction of any court, and its default of duty cannot be made the ground of action, except by petition. It is obvious, therefore, that no binding right can be established by which the cost of sea defences can be thrown upon the State.

The fundamental question is in effect one of *meum* and *tuum*. Who is to foot the bill? The contention on the one side is that, as the defence of the shore is legally a State matter, the private owner should be relieved of its cost. On the other hand, it is urged with reason that the owner of seaside lands in the majority of instances has purchased such lands at a capital figure based upon the risk of incursion, both buyer and seller being aware of the possibility of such inroads recurring. The same argument in a somewhat lesser degree applies to throwing the obligation of maintenance on the particular county affected. The landowner 20 miles from the seashore asks how it can be considered equitable that a scot should be levied on his land in order to provide funds for safeguarding the estate of his neighbour 20 miles away?

Up to a few years back the legal situation was somewhat chaotic. Under the Crown Lands Act of 1866 the management of most foreshore lands passed from the Commissioners of Woods and Forests to the Board of Trade. Up to this date the removal of shingle and sand from the foreshore by authority of the lord of the manor went on almost without let or hindrance. It was often a highly profitable privilege, and the lord of the

manor, having been undisturbed in the custom, legal prescriptive right was asserted, overriding any hypothetical claim of the Crown to exercise jurisdiction. The late Lord Farrer (then Sir Thomas Farrer), in a memorandum to officials of the Board of Trade, was careful to explain that the rights of the Crown rested on a somewhat doubtful assumption, and that, in the assertion of those supposed rights, great caution must be exercised to avoid possible litigation.

The subject is now ripe for statutory action, and the recommendations of the Royal Commission are available as the basis of such legislation. Within the ambit of this handbook their principal recommendations are as follows:—

1. On the subject of accretion and depletion as affecting title, the law to be amended so as not to deprive the Crown of accreted ground where there is well-defined ascertainable boundary to the land of a contiguous owner.

2. That the Board of Trade should have the sole administrative control of foreshores.

3. A clear right of passage by foot along the foreshore, subject to the control of the Board of Trade, is recommended; and, in respect of the rights assumed to exist for bathing, riding, driving, collecting seaweed, &c., it is suggested that the Board of Trade should be given executive authority.

4. On the wide question of the executive administration and active maintenance of the foreshore the Commission quote in summary the suggestion for creating *ad hoc* authorities. This scheme made provision for the division of the coast-line into districts,[1] each district being administered by bodies of County Coast Commissioners and a district engineer or coast warden, whose recommendations would be subject to the central control of a chief engineer under the ægis of the Board of Trade.

A scheme of equitable division of the cost of shore works was also evolved.

Other recommendations were for placing practically complete control in the hands of the respective County Councils.

The report of the Commission is in favour of making the

[1] "Memorandum with regard to the Proposed Creation of Coast Commissioners" (A. E. Carey), Appendix No. XVII.

Board of Trade the central authority in respect of coast protection, giving the Board jurisdiction over—

(1) The removal of shore materials;
(2) The construction of works on the shore;
(3) Assistance where necessary in respect of supervision of existing authorities concerned with coast protective works, and the creation of new authorities in particular areas where found to be desirable.
(4) The Commissioners recommend that the Board of Trade should be "equipped with expert engineering advice, and that provision should be made by the Board for establishing suitable arrangements for the watching of the coast".

The Board of Trade would under these recommendations be constituted the sole Sea Defence Authority of the Realm.

In respect of monetary assistance, the following is the finding of the majority of the Commission:—

"With regard to the borrowing of money for sea-defence purposes by existing local authorities, including Commissions of Sewers in England and Wales, or by new sea-defence authorities to be formed by the Board of Trade, we recommend that the State, as represented by the Public Works Loan Commissioners in England and Scotland and by the Commissioners of Public Works in Ireland, should be empowered in suitable cases and with proper conditions to adopt the policy of making loans for sea-defence purposes on the security of the rates, where the credit, in the opinion of the Public Works Loan Commissioners or the Commissioners of Public Works in Ireland, as the case might be, was good.

"We think that it is undesirable that the supervision of the financial transactions of local sanitary authorities, at present exercised in England and Ireland by the Local Government Boards for those countries, should be taken away from those Boards. We, however, recommend that, in fixing the periods of repayment of loans for sea-defence purposes, those Boards should accept and act upon the report of the Board of Trade with regard to the design of any proposed sea-defence works for the purpose of which a loan is being raised, and also with regard to the probable life of such works. It is desirable to avoid as much as possible two separate inquiries in these cases by the Board of Trade and by the Local Government Boards. Moreover, the practice of the Local Government Board for England of allowing not more than ten years as the period of repayment of loans for groynes, and twenty years for solid defence works, appears to us to operate detrimentally in the case of many local authorities."

They further state: "We are not prepared on the evidence laid before us

to recommend that there is any case for going further and for making grants from public funds in aid of sea defence. . . . We cannot see that there is any ground for the contention that sea defence is a national service; it is true that there is serious erosion in places, but this erosion does not affect the nation at large."

If statutory effect is given to this last recommendation it will afford but poor comfort to many harassed sea frontagers. They have in effect asked for the bread of material assistance, and will be offered the stone of departmental supervision. In the main the recommendations of the Commission amount to little beyond a delegation of authority.

It is obvious that any organized system of administration must, in the interest of the State, be under the control of a State Department, the head of which is responsible to Parliament, and the Board of Trade is pre-eminently the most appropriate public authority in this connection. There is probably no department of the State which is administered with greater efficiency and absence of red-tape restrictions. All those brought into contact with the Harbour Department of that Board recognize the efficiency of its control. At the same time, the Board has at present no organized administration for dealing with the extremely varied functions which would attach to the detailed supervision of the national coast-line. In the management of every façade of seashore knowledge of local conditions is essential, in combination with special expert experience.

The following sequence of events has some bearing on this point. At Hallsands (Slapton Sands), Start Bay, the cliffs and houses were fronted by a beach 150 feet wide, a width of 60 feet of which was from 9 to 14 feet above high-water level. Sea-walls were constructed in 1841, and the beach afforded an effective barrier against inroads of the sea. It is readily demonstrable—

(1) That local conditions of coastal stability had been long-continued;
(2) That any depletion of the protecting medium of defence could not be made good by natural agencies;
(3) That the balance of littoral drift was circumscribed by the Bay, and did not pass either horn of the same.

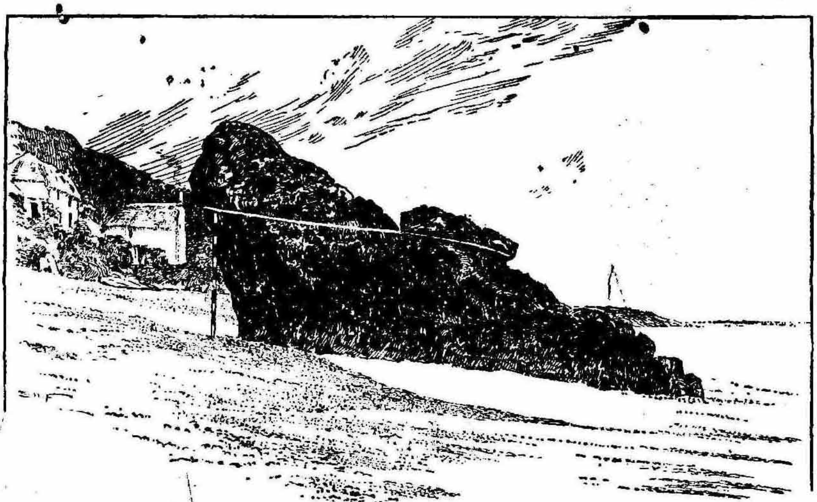


Fig. 52.—Hallsands—Wilson's Rock

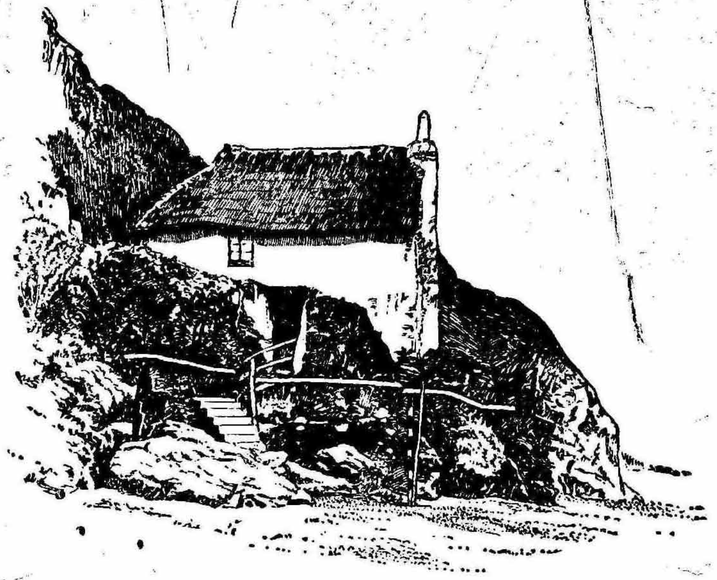


Fig. 53.—Hallsands—Northernmost House

In 1896 Sir John Jackson entered into a contract with the Board of Trade, by which his firm was permitted to dredge sand and gravel opposite Hallsands for the purpose of constructions in Devonport Dockyard. Some 650,000 yards appear to have been removed. In 1901 the sea-walls at the south end of the village were undermined, and the beach level was found to be reduced 7 feet in height. At Wilson's Rock the corresponding reduction in height was 12 feet. In the following year the sea-wall fell, and by definite stages the wrecking of the coast-line progressed. The *coup de grâce* to the entire hamlet of Hallsands was given in a violent north-easterly gale in January, 1917.

It will thus be noted that, under the specific authority of the Board of Trade as now constituted, authority was granted to carry out operations, the effect of which was for practical purposes the destruction of a coast-line of immemorial stability.

Plate XXVIII and figs. 52 and 53 illustrate the sequence of events. Plate XXIX, the reproduction of a photograph of Hallsands taken in 1917, shows the fifth act of the tragedy and the logical sequel of organized denudation under departmental control.

Speaking broadly, Commissioners of Levels and Sewer Commissioners are bodies whose functions are exercised, without pay or recompense, by country gentlemen. Their procedure may be in some instances antiquated in form, but public affairs in their hands are, in the vast majority of cases, administered with economy and fairness. In spite of many notable instances to the contrary, small corporations and urban district councils have not proved themselves ideal instruments of government. Men of administrative capacity are apt to hold themselves aloof from their deliberations. It would be distinctly a retrograde step to increase the power of the urban authority at the expense of that of Commissioners of Levels.

In Appendix No. VII, p. 274, is given a list[1] of the Commissions of Levels and of other authorities who exercise statutory control over foreshore lands and lands liable to tidal flooding, and in the case of those marked (*) their jurisdiction abuts on the sea-coast.

These authorities, however, have jurisdiction only over

[1] See Appendix XLIV of *Report of Royal Commission on Coast Erosion.*

Plate XXVIII

HALLSANDS IN 1894

After R. Hansford Worth

HALLSANDS IN 1904

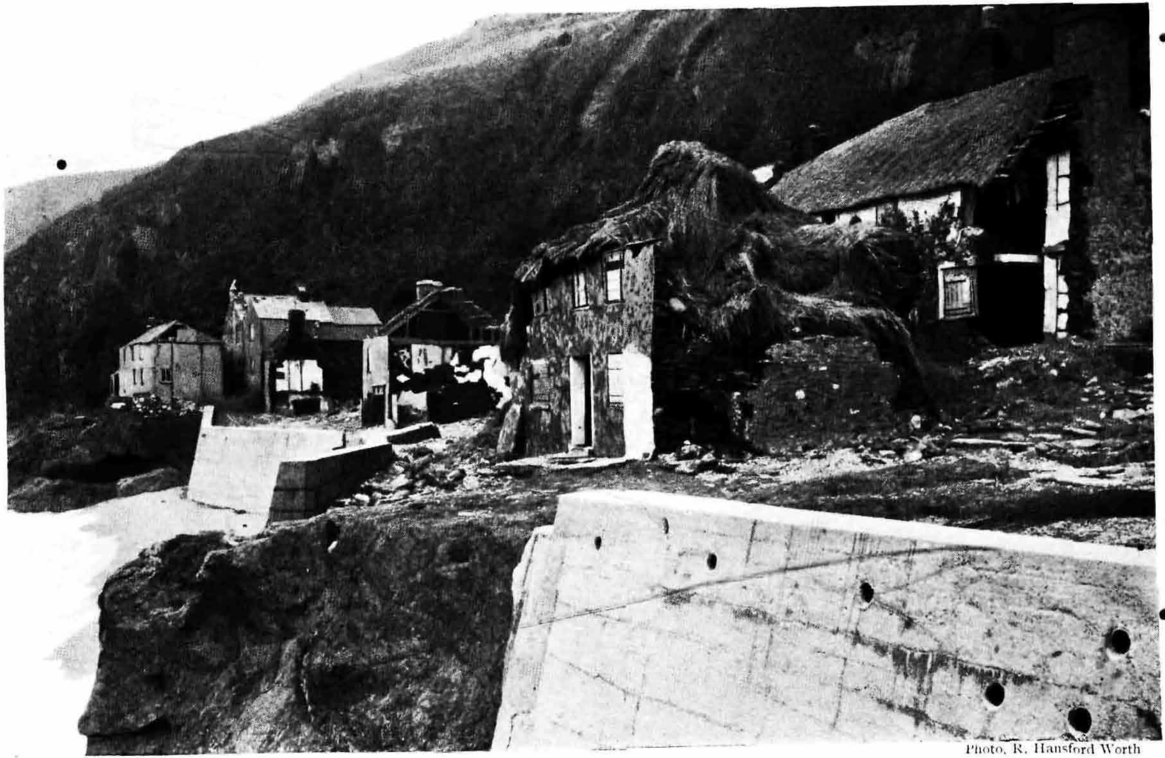
The two pictures are from the same view-point, and the state of the tide is the same in both. By 1904 the beach had fallen about 10 feet

isolated fragments of the foreshore. Corporations and Urban District Councils also exercise a limited control over considerable frontages, but, eliminating the areas of local and restricted authority, there still remain great stretches of tidal and coastal façades which are left under no effective supervision. The poorer agricultural and town districts are the most neglected. The effect of this sporadic system of control is an unscientific frontier, defended in patches merely, alternating with unguarded stretches of coast-line. Thus while a township or particular estate may be carefully fended against attack, it is frequently liable to outflanking by the erosion of contiguous properties to leeward of it. It is admitted on all hands that present methods of administration need overhauling. In England and Wales, in addition to the Commissioners of Sewers appointed under the Crown, there are elective Drainage Boards constituted under the Land Drainage Act of 1861, and under private Acts of Parliament other similar bodies of Commissioners have been nominated or elected.

Harbour authorities in many cases exercise jurisdiction, as well as county and borough councils, and urban, district, and rural councils. The present necessity is for an organization which will link up all these various disjointed authorities and give them co-ordinate and collective control. The powers of Commissioners of Sewers mostly date back to 23 Henry VIII. That Act has been varied by five subsequent Acts. Under the Land Drainage Act of 1861 powers are provided for the maintenance and improvement of existing works and the construction of new works. A tract of uncontrolled frontage can, however, only be brought "under commission" by the consent of two-thirds of the landowners affected. The procedure of Commissions of Sewers varies in different localities. Their general borrowing powers fall under the sanction of the Board of Agriculture and Fisheries. In some cases orders to ensure current repair are made on the respective landowners concerned, who are directed to carry out the works specified under penalty for default. On works of small cost the penalty is usually double the estimate; for works exceeding £20, 50 per cent in excess of such estimate. The Commissioners meet periodically; in most

cases they are represented by a professional engineer, on whose "presentments" the Court orders are issued. One or more Marsh Bailiffs hold office, and the duty of these officers, who are resident in the area affected, is to make constant inspection and supervise the execution of orders of the Court. If organizations similar in procedure to these Courts could be extended over all areas affected by erosion, and some measure of concerted action devised, it is safe to predict that the coast erosion problem would disappear. The bane of the elected authority is inefficient compromise in the face of obstruction. In many cases obvious requirements have thus been contested until disaster impended. The plea usually put forward in these cases is that of economy. It is frequently an economy of the inverted type. Scattered up and down the coast-line are many local authorities whose actions are models of business-like administration, but it is safe to say that, speaking broadly, government by Commissioners of Levels is at the present time the most efficient form of control in respect of a threatened coast-line. In some cases the Commissioners of Levels themselves carry out the necessary defence works, and either charge the cost of the same on the individual landowner concerned or allocate the collective cost by scot over the entire level *pro ratâ* on the areas of occupation. To a large extent this is a matter of custom. Probably the most economical arrangement is for each body of Commissioners to institute a works department of its own. Commissioners have skilled men in their employ, and are able to buy materials and secure the necessary plant more economically than the individual landowner. On the other hand, the landowner is generally the employer of agricultural labour, and can carry out orders economically in the off seasons. Where the present system works smoothly, the principle *quieta non movere* would appear to be the soundest. There is no doubt that the districts controlled by the Commissioners are in some cases badly delimited, and that a reorganization of the whole system would be desirable. All who have had practical experience of the working of coastal bodies will agree that, as a broad principle, the government by country gentlemen compares favourably with that of elected town bodies.

Plate XXIX



Photo, R. Hansford Worth

HALLSANDS IN 1917

Mr. Hansford Worth communicates the following note with this photograph of Hallsands: " In addition to the ruins actually visible

It is eminently desirable that the operations of local bodies of control should be under the ægis of a central authority, to counteract the more parochial view of the duties of governance. The whole situation is very similar to that of a campaign, in which each individual unit has to be controlled and directed by the general staff, which alone is able to co-ordinate the combined chain of defence.

Reverting to the question of how the cost of foreshore works is to be met, and the collective apportionment of such cost, the Coast Erosion Commission has, as already stated, reported in favour of making the Board of Trade the Central Authority, and of giving the Board power to provide expert advice in London and locally. Their report carries with it in principle a recommendation that the State should pay what may be termed the head-quarters staff and its immediate delegates, in this case the coast wardens. By slightly extending this liability to cover the cost of requisite plant, the necessity of the case would probably be met. The defence of a threatened line of coast is surely a matter toward which a moderate contribution from the funds of the County Council concerned might be properly applied. A sound rule would appear to be that the County expenditure should be limited, say, to a halfpenny rate. The balance of expenditure might very fairly be thrown on the townships and owners (whether individuals or companies) of the affected frontages.

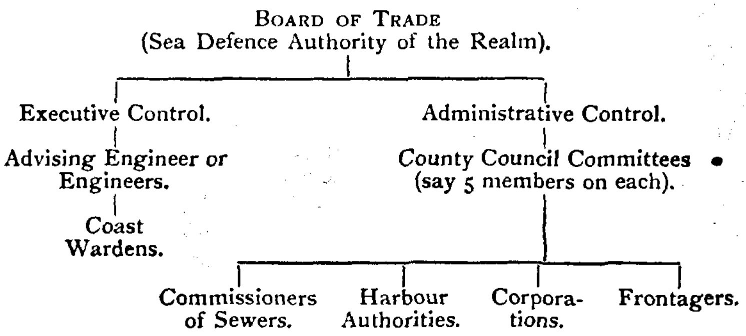
One subsidiary source of funds might fairly be tapped. The feudal system under which, when an estate changed ownership, a defined percentage of the purchase price was payable to the overlord, would appear to be a sound one in this case. The principle is similar to that of succession duty on demise. Probably if it were a standing rule that, whenever an estate on the threatened area (not being town-land) was sold, 2½ per cent of the cost of purchase should be paid to the Coastal Defence Fund, such dole would not press unduly on the individual owner.

Speaking generally, the sound policy would appear to be:—

Local Control.—1. To strengthen and, where necessary, reform the operations of existing Level Commissioners and readjust their areas of control.

2. To make provision for the effective control of the operations of Corporations and Urban and District Councils, so that all parties may work in harmony.

Central Control.—To organize a system of delegation of control on the following basis:—



The powers which would have to be conferred on the united authorities, central and local, would include the following matters:—

1. To take observations, keep records, make inspections and surveys, and public reports, plans, and other documents, for the collective guidance of coastal authorities.

2. To make by-laws, subject to the sanction of the Board of Trade, for the following purposes:—

(*a*) Preventing, restricting, and regulating the removal of sand, shingle, and other materials;

(*b*) Regulating the draining of lands contiguous to the coast-line, and as far back as may be necessary to prevent injury to the cliffs or seashore;

(*c*) Controlling the design and construction of any works for protecting cliffs or seashore;

(*d*) For any other purposes which in the opinion of the Board of Trade may be necessary for the due protection and maintenance of the seashore and coast-line, whether above or below high-water levels.

3. To enforce such by-laws as may be approved by the

Board of Trade, and take proceedings for any offences in respect of such by-laws.

4. With the sanction of a provisional order of the Board of Trade, confirmed by Act of Parliament, to make, maintain, remove, or alter any works designed or executed for the protection of cliffs or the seashore, whether above or below high-water levels, and to formulate such conditions as will permit of the removal and transfer of surplus shingle or other materials where the surplus exists to another part of the seashore where the same is depleted.

5. To promote Provisional Orders for obtaining power to execute works, acquire lands and interests in lands compulsorily, appropriate lands reclaimed by means of coast protection works, and exercise control over a coast-line and such works within the coastal area as are affected thereby.

6. To promote and oppose bills in Parliament dealing with matters which may affect the interests or fall within the purview of the Coastal Authority.

7. By agreement with owners or local public authorities, or under powers of Provisional Orders, to plant and develop vegetation on cliffs or a seashore, whether above or below high-water level, and arrange for the cultivation and fertilization of the same, and of any coastal or tidal lands which may be thereby reclaimed.

8. To employ engineers, coast wardens, and other officers whose services would be required to carry into effect the objects of the Act.

9. To devise and carry out experiments in protective and reclaiming procedure, and establish such experimental stations as may be deemed by the Board of Trade expedient, in order that the protective function of shore plants and their value in respect of land reclamation and maintenance may be investigated, and also to empower the publication of reports or detailed information which may be of public service in connection with the coastal or riparian regime.

10. To buy by agreement, or make provision for the reclamation of tidal or coastal lands, or lands useful or necessary for the purposes of coast protection, or such lands as in the

opinion of the Board of Trade fall within the scope of a scheme of reclamation, or be improved in value by reason of the existence or in the event of the construction of coast protection works.

11. To hold, lease, sell, or otherwise deal with any land acquired or reclaimed under the operations of the Act.

12. With the sanction of a Provisional Order to enter into and carry into effect agreements with landowners or local public authorities for loans from the Public Works Loan Commissioners, or which may be subscribed by the public, or grants of money made by the Treasury, either as capital or annual payments, by way of contribution towards the cost of any works for coast protection to be executed by such landowners or public authorities under the direction of the Board of Trade.

Funds.—1. Funds voted by Treasury.

2. Grants (for capital expenditure) from the Development Commissioners.

3. Grants (under authority of Provisional Order) for either capital or current expenditure from local public authorities, companies, or persons.

4. Rates or scots on owners of property in defined areas benefited by particular works.

5. Precepts on county funds, but such precepts not to exceed a total rate of ½*d.* in the £ on the rateable value of such county.

6. Loans (for capital expenditure) from the Public Works Loan Commissioners, secured *pro ratâ* on the rates of the local authority concerned, or on the credit of the landowners, whether companies or individuals.

7. Income from investments representing capital grants or other capital moneys.

A concrete instance of successful combined action is furnished in the Report of the Royal Commission. Under the Newhaven and Seaford Sea Defences Act of 1898 provision is made for a combination of local authorities, public companies, and private persons for the purpose of sea defence. The Commissioners appointed under this Act are a body corporate with perpetual succession and power to purchase and dispose of land

and other property. It is noted in the report of the Commission, that the scheme has worked with complete smoothness. It thus constitutes an excellent object lesson in the combination of interests which is essential in dealing with a composite problem such as that of coast erosion. Summarizing the situation, it may be fairly maintained that:—

1. It is admitted that the State has an exceptional duty to the owners of land contiguous to the sea, whose land is liable to its invasion.

2. The counties concerned cannot fairly adopt the policy of benevolent neutrality towards the lands threatened by irruption of the sea, as to do so would in many instances be to risk far-reaching damage to inland tracts, which in their turn would suffer if the sea broke through.

3. The municipalities bordering on a coast-line often find themselves heavily burdened by taxation to maintain their frontage intact, and it would certainly appear to be equitable that they should be parties to any concerted action in respect of defence.

4. The individual landowners or land-owning companies are in many cases in an even worse plight than corporate bodies, and, as a result, the property they own frequently drifts into a half-derelict condition. The declension of good agricultural land to prairie is a matter of prime importance to the community.

It is patent to all the world that new problems and fresh methods of governance are opening out in every department of human activity. Old methods of meeting difficulties are being tacitly abandoned. New ideals are fermenting in all regions of British activity. Under the compulsion of world changes, modern England cannot be content indefinitely to traverse routes that sufficed for former generations. It is in the adoption of the principle of corporate responsibility that the problems of the future will have to be faced.

CHAPTER XIV

Complementary Problems

The death grapple of a world war has modified many ideals and rendered obsolete panaceas springing from a national creed of *laissez-faire*. Great Britain is the microcosm of the world. Her home resources of coal, iron, salt, stone, fireclay, and other earth products, combined with a virile population of ordered industry and her unrivalled system of harbours and sea inlets, gave her a long start in the race of commercial supremacy. The collapse in agricultural output, and the consequent shrinkage in the value of rural lands following on the theories of the Manchester School, accompanied, as they necessarily were, by a rapidly progressive increase in the importation of food and other essentials of life, and also in the number of unemployed in the Homeland, constituted an economic revolution of far-reaching effect. In this connection the problem of water-transport facilities, both overseas and coastwise, has loomed progressively insistent. Great Britain led the world in a sequence of industries. She was the first to perfect her system of roads. She then led the way in the provision of water carriage by canal. Railway connection, having its inception in England, boomed there, and she became the nurse of similar undertakings in other countries. Lastly, mechanical road traction has been perfected by her. In every link in the chain of development she has been more quickly overhauled in the race by rival nations. The old days of "rest and be thankful" are at an end. An improvement made in any country becomes speedily the common property of the world, to be reproduced in remote corners of the earth. An American motor-car traversing a

native-built Chinese road is typical of the trend of economic change at the present day.

In one field Great Britain has, however, hitherto assumed and retained her supremacy, namely, that of shipbuilding. She has lagged behind her competitors in the volume of production in many departments of prime industrial importance. In spite of the fact that she has held the reins as the banker and commercial exchange centre of the world, she has been eclipsed in some directions by her own sheer inertness, whole classes of manufacture which she originated having been let slip by her. In some quarters she has to learn to reverse her Victorian policy of masterly inactivity. War has revealed the inevitable path of ordered change. It becomes increasingly obvious that many treasured trade traditions must float away in the smoke of battle. By combined effort the State, organized Capital, and organized Labour must march together in the acute problems of the future.

Amongst these problems none takes precedence of that of national waterways and harbours. How are these to be organized so as to render most vital service in coming emergencies?

The efficiency of a great arterial system of waterways is largely an index of commercial progress. This is essentially true in a congested country such as England. A few years ago belated proposals were put forward for bringing back the canal system of this country to its ancient position as universal carrier. It is now pretty widely admitted that the minor canal in England has more or less had its day. The railways have practically monopolized the means of transport, and canals serve in the main as feeders to the railways. Even this hybrid condition of things probably will not persist. In a certain restricted number of cases, and in respect of certain minor trades, where delay in the transit of goods is of lesser importance, the older canals may continue partially to serve their original purpose.

The substitution of steam, petrol, or electric motor traction would probably necessitate heavy expenditure in the reconstruction of the banks of those designed for slow horse traffic.

The ship canal is a proposition of a totally different character. It is probable that schemes for the creation of inland ports and distributing centres will become more insistent. Such towns

as Colchester and Norwich may be instanced. Where physical conditions are favourable, and the cost of cutting a deep-water canal to a great industrial centre is likely to be low, projects for creating such facilities will certainly demand attention. Canals such as those for connecting the Clyde and the Forth will also doubtless come to the front, not only by reason of trade conditions, but on defensive grounds.

In the matter of fishery harbours the State has come to the aid of many localities, assisting local endeavour by grants and loans. Closely connected with these problems is that of the official control of the foreshore. Matters will probably not be allowed to continue much longer on their present haphazard basis. The report of the recent Royal Commission was of a somewhat hedging and tentative character, reflecting the pre-war attitude. The upheaval of idea and method which has resulted from war expenditure will upset the more timorous notions of the past. A national policy to be of value must be fundamental and to some extent run risks. In this connection the many problems attacked in this book will doubtless seek solution. It is obviously impossible to carry out a successful campaign on a large scale, with the object of tuning up the waterways and tidal reaches of the countryside, without systematic investigation. The vested interest of an inland trade centre may be best served by carrying deep-water facilities to that centre. In many instances the reverse is the case. Counsel fighting in the committee rooms over such issues constitute a poor substitute for the patient, trained, and organized investigation of a scientific public authority. The trade of London is a case in point. This is fast changing in character. The manufactures which have hitherto centred in the Metropolis are being rapidly decentralized, and the outflow of these manufacturing trades is being spread over inland districts. Thus the dominance of railway transport tends to increase.

The character of inland ports varies greatly. Of the trade of London about 74 per cent of the goods are lightered *ex* ship to warehouse. The cheap tidal transport of goods on the Thames and its vast facilities for lighterage traffic have in the past rendered London a cheap port for the bulk of the com-

modities to be catered for. On the other hand, on ships entering the London docks charges have been excessive. A costly programme of works has been initiated by the Port of London Authority with the object of deepening the river and bringing the upper docks up to date. It is highly probable that a well-devised scheme under which deep-water traffic would have been concentrated in the lower reaches of the river, where deep water naturally exists, could have been evolved, the transport by lighter to warehouses and upper docks being left undisturbed. Thus economy in distribution would have been realized and vast capital expenditure avoided. However, the transfer of the docks to State ownership and the creation of the Port of London Authority have taken place, and expansion of the trade has so far kept pace with and thus justified the changes effected.

Liverpool is in a totally different position. There the traffic is in the main that of vessels of great tonnage, and the goods are handled direct *ex* ocean-going ship to warehouse.

The vast increase in recent years in the shipping facilities of Southampton demonstrates how all-important physical conditions are in determining the type of shipping accommodation which it is desirable to provide. The latest addition to that port was that of a deep-water basin having a total frontage of 4637 feet and a depth alongside at low water of 40 feet. The principle of deep-water quayage has, by its construction, been confirmed. The peculiar tidal conditions existing at Southampton, and the unique shelter due to its geographical position in regard to the Isle of Wight, have largely shaped its development. The tidal conditions at Southampton are such that at spring tides the tide, after ebbing at the rate of about 3 feet per hour to its lowest point, at once commences to rise at about the same rate. At high-water level it is practically stationary for about three hours. The double tide in Southampton Water is the result of the travel of the tide, passing first round the north-western shoulder of the Isle of Wight, and then round its north-eastern shoulder, thus encircling the island and causing a meeting of the consecutive floods and effecting a welling-up of the water at Southampton. The facilities of the port are thus almost unique.

If a public body constituted *ad hoc* took in hand the control of foreshores and tidal waters for directional purposes, continuity of policy and definiteness of aim should be achieved. To form these interests into an extension of an existing department, however well administered such may be, might result in an accentuation of existing difficulties rather than in their elimination. Such a department has in the long run to depend on the chance advice of inspectors appointed, as occasion requires, for particular enquiries. Thus it often comes about that a railway engineer, or an engineer whose experience has been in some entirely different channel, has to advise the department on intricate physical questions in reference to a locality which he has but casually visited. What is to be aimed at is to build up a bureau which would be in a position to amass all the necessary data, to study them steadily and in sequence, and to deal with any individual problem which may arise as an organic unit in a comprehensive scheme of coastal economy. The sporadic method of disposing of difficulties leads to many complications, not the least being that conflicting and irrelevant local issues often loom far larger than their value justifies. The rule "what's best administered is best" is after all in many directions a golden rule.

Indiscriminate land reclamation has frequently ruined good waterways. Over and above the training of waterways, the prevention of flooding, the maintenance of outfalls, and the inning of lands contiguous to tidal waters, there are questions of research which will probably have considerable bearing on future issues. Thus the question of the utilization of sea plants for the purposes of paper-making may well form a side issue in dealing with local conditions. The study of long-shore vegetation and its function in relation to the design of public works is largely a new departure. No department can be efficient which fails to study the application of vegetal growth to specific purposes of development. It would, in fact, perform the function in respect of tidal waters which a Forestry Department does in the afforestation of land surfaces.

Air Reefs.—One of the most striking departures in sea work of recent years is the Brasher system of compressed air, for

stilling an area of disturbance in the open sea or other exposed waters. Similarly it is efficient in the protection of shores liable to erosion. This system has been adopted with success in America, notably by the Standard Oil Company at El Segundo, California. Its resultant effect is to produce an area of still water by means of the ejection of air from perforated pipes laid on the sea bed. At El Segundo the pier, as built, was 4000 feet long, and in the winter of 1914–5 a length of nearly 2000 feet of it was washed away. In this instance the submerged perforated pipes subsequently laid for its protection were served by existing compressors, and a shield or wall of air, rising from the bed of the sea to the surface, was created. This air reef neutralized the sea disturbance, producing sufficient tranquillity to permit vessels to load or discharge at the pier in stormy weather.

From installations already carried out the cost of the application of the system appears to be about £2 to £4 per lineal foot.

It is obviously only necessary to put the apparatus in operation in rough weather. When the sea or other exposed area of water is naturally tranquil, craft can lie alongside a jetty or quay to discharge or load, without let or hindrance. On the approach of doubtful or stormy weather, the compressed air is switched on and still water results. A ship at the jetty thus lies surrounded by broken water, but in a lagoon of safety.

The applications of the air method are varied. Not only is it available for protecting shipping made fast to a pier in the open sea or otherwise, but it can be used during the construction of sea-walls, piers, lighthouses, &c., to produce artificial tranquillity, and thus enable operations to be carried on undisturbed. Stranded vessels can also be protected from the pounding action of the waves, and round lighthouses or lightships a tranquillized area of water, as occasion demands, can be created.

The cost of operating the apparatus is small. At El Segundo, during a heavy winter storm, the plant was in operation for twenty-three hours at a cost of £12.

One important application of the system is that of protecting

dredgers in exposed places during rough weather, and thus enabling them to carry on their work undisturbed.

A trial of the Brasher invention during the raising of the U.S.S. *Yankee* was described by an eye-witness as follows:—"The heavy breaking seas were powerless to pass the line of air. Before the air was turned on the seas were boarding the ship fore and aft, causing it to grind very much on the rocky bed, and making work very disagreeable. After the air was turned on in the breakwater it was as though the ship was in a lagoon formed by the sea breakwater, while seas were breaking heavily outside."

The success of the system depends on the neutralization of the oscillatory impulse of waves in deep water. Each of the bubbles forming the air screen as it rises to the surface has an explosive action. These collectively disrupt the wave mass, and disturb the continuity of its particles in such a manner that the wave beats out of time, and losing its rhythm, its rolling motion is automatically brought to a deadlock. An ingenious explanation of the action is contained in a letter to *The Engineer*, dated 9th June, 1916. The theory evolved by the writer is that, as the effect of a current of air passing over a rounded surface is to cause some increase of pressure on the windward side and a corresponding reduction of pressure on the leeward side, the emission of a column of air rising from the bed of the sea under pressure upsets the plus and minus surface pressure conditions set up by the wind passing over wave crests, resulting in these becoming self-destructive, with the effect of stilling the forces of oscillation.

APPENDIX I

List of Dune Plants

Pioneers on Moving Sand:—

Elymus arenarius (Gramineæ).
Psamma arenaria (Gramineæ).
Salix repens (Salicaceæ).
Festuca rubra (Gramineæ).
Carex arenaria (Cyperaceæ).
Euphorbia Paralias (Euphorbiaceæ).
Eryngium maritimum (Umbelliferæ).

Pioneers Restricted to Strand:—

Triticum junceum (Gramineæ).
Arenaria peploides (Caryophyllaceæ).
Salsola Kali (Chenopodiaceæ).
Cakile maritima (Cruciferæ).

On Resting Sand:—

Polypodium vulgare (Filicineæ).
Pteris aquilina (Filicineæ).
Corynephorus canescens (Gramineæ).
Luzula campestris (Juncaceæ).
Asparagus officinalis (Liliaceæ).
Rumex Acetosella (Polygonaceæ).
Cerastium semidecandrum (Caryophyllaceæ).
Sedum acre (Crassulaceæ).
Rosa pimpinellifolia (Rosaceæ).
Ononis repens (Leguminosæ).
Lotus corniculatus (Leguminosæ).
Hippophae Rhamnoides (Elæagnaceæ).

Sambucus nigra (Caprifoliaceæ).
Ligustrum vulgare (Oleaceæ).
Convolvulus Soldanella (Convolvulaceæ).
Cynoglossum officinale (Boraginaceæ).
Thymus Serpyllum (Labiatæ).
Solanum Dulcamara (Solanaceæ).
Euphrasia officinalis (Scrophulariaceæ).
Galium verum (Rubiaceæ).
Anagallis arvensis (Primulaceæ).
Jasione montana (Campanulaceæ).
Senecio vulgaris (Compositæ).
Senecio Jacobæa (Compositæ).
Cnicus arvensis (Compositæ).
Cnicus lanceolatus (Compositæ).
Hieracium Pilosella (Compositæ).
Taraxacum officinale (Compositæ).
Erodium cicutarium (Geraniaceæ).
&c. &c.

Mosses:—

Tortula ruraliformis.
Ceratodon purpureus.
Hypnum cupressiforme, &c.

Lichens:—

Peltigera canina.
Cladonia furcata.
Cladonia rangiferina, &c.

Ephemerals (*resting sand*):—

Veronica hederifolia (Scrophulariaceæ).
Veronica agrestis (Scrophulariaceæ).
Saxifraga tridactylites (Saxifragaceæ).
Cerastium glomeratum (Caryophyllaceæ).
Cerastium tetrandrum (Caryophyllaceæ).
Sherardia arvensis (Rubiaceæ).
Myosotis collina (Boraginaceæ).
Draba verna (Cruciferæ).
Phleum arenarium (Gramineæ).

APPENDIX II

Types of Shingle Beach (English)

Spits:—

Hurst Castle and Blakeney (with hooks).
Northam, Spurn, Aldeburgh, Hamstead (Isle of Wight), Cammaes (Anglesea).

Bars:—

Chesil, Pevensey, Slapton.

Apposition:—

Dungeness, Aldeburgh (Orfordness), Pevensey (Langney Point).

APPENDIX III

Plants of the Shingle Beach

Mobile Shingle:—

Silene maritima.
Glaucium luteum.
Rumex trigranulatus.
Sedum acre.
Crambe maritima.
Geranium purpureum.
Lathyrus maritimus.
Atriplex patula.

Suæda fruticosa Artemisia maritima Statice Limonium Plantago maritima	Halophytic element.
Ranunculus bulbosus Polygonum amphibium	Element from freshwater marshes, and meadows.

Arenaria peploides—where much sand present.
Psamma and Elymus—as dune relics.

Solanum Dulcamara.
Convolvulus Soldanella.
Mertensia maritima.
Beta vulgaris.
Festuca rubra.
Triticum junceum.

Stable Shingle:—

Arrhenatherum avenaceum.
Galium Mollugo.
Galium verum.
Lotus corniculatus.
Sedum acre.
Galeopsis Ladanum.
Echium vulgare.
Statice binervosa.
Armeria maritima.
Sambucus nigra.
Ulex europæus.
Cytisus scoparius.
Cratægus monogyna.
Rubus fruticosa.
Prunus spinosa.
Ilex Aquifolium.
Triticum pungens.
Inula crithmoides.
Artemisia maritima.
Plantago Coronopus.
Plantago lanceolatus.
Holcus lanatus.
Festuca rubra.
Agrostis maritima.
Trifolium arvensis.
Rumex Acetosa.
Rumex Acetosella.
Digitalis purpurea.
Ballota nigra.
Urtica dioica.

Lichens:—

Verrucaria maura.
Rhizocarpon confervoides.
Buellia colludens.
Physcia parietina.
&c.

APPENDIX IV

Plants of the Salt Marsh

Algæ:—

Rhizoclonium.
Enteromorpha.
Vaucheria Thuretii.
Lyngbya.
Microcoleus chthonoplastes.
Fucus vesiculosus, forms—volubilis, limicola, muscoides.
Fucus balticus.
Pelvetia canaliculata, forma libera.
Ascophyllum nodosum v. scorpioides.
Bostrychia scorpioides.

Angiosperms:—

Salicornia annua (Chenopodiaceæ).
Salicornia ramosissima (Chenopodiaceæ).
Salicornia radicans, &c. (Chenopodiaceæ).
Suæda maritima (Chenopodiaceæ).
Obione portulacoides (Chenopodiaceæ).
Glyceria maritima (Gramineæ).
Spartina stricta (Gramineæ).
Spartina Townsendii (Gramineæ).
Triticum pungens (Gramineæ).
Scirpus maritimus (Cyperaceæ).
Cochlearia officinalis, &c. (Cruciferæ).
Statice Limonium (Plumbaginaceæ).
Statice humilis (Plumbaginaceæ).
Statice reticulata (Plumbaginaceæ).

Armeria maritima (Plumbaginaceæ).
Glaux maritima (Primulaceæ).
Samolus Valerandi (Primulaceæ).
Aster Tripolium (Compositæ).
Artemisia maritima (Compositæ).
Spergularia media (Caryophyllaceæ).
Spergularia salina (Caryophyllaceæ).
Plantago maritima (Plantaginaceæ).
Plantago Coronopus (Plantaginaceæ).
Frankenia lævis (Frankeniaceæ).
Juncus maritimus (Juncaceæ).
Juncus Gerardi (Juncaceæ).
Triglochin maritimum (Naiadaceæ).
Zostera marina and nana (Naiadaceæ).

APPENDIX V

Salt Marsh Development

Varies with locality and substratum. In the examples given the numbers indicate the order of the phases or "successions".

I. Mud.

Bouche d'Erquy:—

(1) Salicornia ramosissima + Rhizoclonium.
(2) S. ram. + Glyceria maritima ("Crimson Plain").
(3) S. ram. + Glyceria marit. + Suæda maritima.
(4) Glyceria + Armeria + relics of (3).

Blakeney Point:—

(1) Salicornia annua + Pelvetia libera.
Marginal zone with accretion: Suæda maritima, Salicornia radicans, Obione (dwarf), and relicts of (1).
(2) Salicornia + Aster.

(3) Mixed Salting (Statice Limonium, Spergularia media, Triglochin, Plantago, Glyceria).
(4) Obione (high) + relicts of (3).

Blakeney Point:—

(1) Enteromorpha sp.
(2) Fucus limicola, Salicornia annua (Enteromorpha). (Pelvetia libera would come in here.)
(3) Salicornia + Aster.
(4) Mixed Salting.

II. Sand.

Bouche d'Erquy:—

(1) Salicornia radicans hummocks; bare between (perennial).
(2) S. rad., Glyceria, Suæda maritima, &c.; Salicornia ramosissima (annual; in the troughs).
(3) Glyceria + other halophytes.
(4) Rolling turf of Glyceria with Sd. mar. and other halophytes.

Arnside:—

(1) Glyceria maritima hummocks.
(2) Glyceria + Lepturus filiformis and Agrostis alba v. marit.
Spergularia media, between the hummocks, and later Aster.
(3) Festuca rubra v. pruinosa, Lepturus and Agrostis + Aster, Plantago, Armeria.

APPENDIX VI

On the Distribution of *Suæda fruticosa* at Blakeney Point

From an inspection of the different sections of the main beach it is evident that there is great variation in their degree of sterility. For a complete explanation it would be necessary to consider every species of plant in relation to the conditions obtaining on each section of the beach—a subject too exhaustive to be entered on here.

The case of *Suæda fruticosa*, an outstanding plant on Blakeney Point, may, however, be taken in some detail, and will serve at the same time to illustrate the kind of circumstances that are significant in the distribution of any species of plant.

The various sections of the Main Beach and the occurrence of Suæda are indicated on the accompanying diagram (fig. 54), which represents in simplified form a chart extending from the reclaimed marshes opposite Salthouse in the east to and including the Hood in the west. This stretch, actually over 4 miles in length, includes all the different types or combinations of conditions which the Blakeney beach provides.

Each section will be considered here in relation to the two fundamental conditions which must be satisfied if Suæda is to become established—

(*a*) The facilities for the introduction of seed to the lee fringe;

(*b*) The stability of the lee fringe during the period of establishment.

For brevity these are referred to as *inoculation* and *stability*, respectively.

1. *Protected Bays* (Sections B and E, fig. 54).—The peculiarities of these, already referred to (p. 235) for the Marams section (E), are as follows. The talus fans whilst washed by the spring tides, thus receiving their quota of drift and seeds,

are protected from erosion by the hooks. Consequently, the materials of the lee fringe remain quiescent till fresh shingle is shot down from the crest. The intervals of quiescence in recent years have been long enough for the establishment of Suæda bushes. The conditions at B resemble those at E—the fans remain and Suæda establishes. This type of lee fringe is represented on the diagram (fig. 54, B and E) by an unbroken sinuous line, the Suæda plants by dots following the scalloped edge.

2. *Open Bays* (Section C).—These occur east and west of

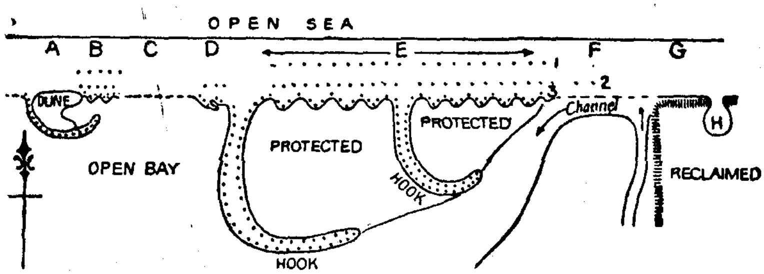


Fig. 54.—Diagram Map of Blakeney Main Beach from the Reclaimed Marshes to the Hood, showing the distribution of Suæda bushes in zones (rows of dots 1, 2, and 3)

The different types of the lee edge referred to in the text occur opposite the letters A to H. A, beach bordered by dune; B and E (sinuous line), dormant fans; C and F (broken line), edge eroded by scour; D, place of accumulation of shingle drifted east from section C; G, beach bordered by sea-wall; H, shingle fan projecting through breach in sea-wall.

the Hood. The lee fringe is not protected by hooks and is liable to scour when the wind blows from the south or south-west. A shingle talus develops in the usual way but is eroded by the waves—the products of erosion in the case of Section C being transported mainly into the eastern corner of the bay at D. The broken line at C indicates this non-permanence of the fans. Suæda bushes have failed to establish along the section, not from want of inoculation—which is perfectly adequate—but because the ground at and immediately below the spring-tide mark has proved too unstable for seedlings to retain a footing.

A change, however, is overtaking this section. In 1913 a line of seedlings could be traced along the talus extending east from Section B for some 200 yards, a position where pre-

viously seedlings were not found. Survivors from these seedlings had by 1916 attained the size of small bushes 12–18 inches high. This increasing stabilization probably depends on the recent rapid rise in level of the Samphire Marsh (south-east of the Hood) and the greater protection from scour thus afforded. Should this tendency continue, it is to be expected that the fringe of this section will in time become entirely colonized by Suæda.

3. *The Bay Corner* (Section D).—As stated, the shingle of the fans that arise on Section C is drifted by the scour into the eastern angle at D, where it accumulates to form a salient. As the same agency brings much vegetable drift and seeds, this corner has become colonized with Suæda under the most favourable conditions.

4. *Beach by Cley Channel* (Section F).—The conditions here much resemble Section C; shingle is brought down from the crest by storms, but the fans are non-permanent on account of the undercutting of the beach by the tidal channel. The eroded material finds its way into the bed of the channel, so that navigation is impeded and difficulty is found in draining the reclaimed marshes which lie between Cley and Salthouse. Here again inoculation is ample, but the mobility is too continuous for the establishment of Suæda plants. It is of interest to note that although the lowest Suæda zone is unrepresented, relics of the upper zones 1 and 2 are still to be found on this section. These vestiges consist in part of a few bushes and also of seedling plants, in position remote from full-grown bushes, whose presence may be due to derivation from bushes which existed before this section of the beach reached its present high degree of mobility.

5. *Beach backed by Sand Dunes* (Section A).—This condition, which is found at the Hood and at the base of the Long Hills and Headland, is marked by absence of Suæda from the main beach. The probable explanation is that the dune, by excluding the tidal drift from the lee side, prevents inoculation.

6. *Beach backed by Sea-wall* (Section G).—East of the point where Cley Channel turns south the main beach is for several miles backed by a sea-wall designed to protect the reclaimed

marshes behind. The whole of this section is free from Suæda, and the reason is probably the same as in 5.

7. *Shingle Fan formed by breaching of Sea-wall* (Section H).—Along the course of the sea-wall, especially opposite Salthouse, numerous breaches have been formed through which extensive fans of shingle have been projected. These fans enjoy long periods of stability, but remain uncolonized by Suæda—the reason doubtless being that even when these fans receive drift from floods in the reclaimed marshes, no seeds of Suæda are included. These flood waters not being in continuity with the system of tidal waters of the estuary which has access to Suæda bushes, the automatic mechanism for bringing a supply of seeds is lacking.

Reviewing all these separate cases it is evident that the actual distribution of *Suæda fruticosa* depends upon the coincidence of two factors—opportunity of inoculation and sufficient stability for the establishment of seedlings. It is also probable that these considerations are in general valid of all kinds of mobile ground.

Other Sources of Inoculation.—The possibility of inoculation from the sea face remains for consideration. Undoubtedly fragments of vegetation, including seeds, are floated out from Blakeney Harbour to the open sea and make their way into the drift of the sea face. The twigs of Suæda bitten off by rabbits are often found here, and in 1913 established plants of a new colonist, *Solanum Dulcamara*, were found among the embryo dunes, still attached to the drifted stems from which they had sprouted. *Mertensia maritima*, one of the great rarities of Blakeney Point, probably came as ocean drift, and the same should hold for specimens of *Convolvulus Soldanella* on the crest of the main beach. Nevertheless these cases are rare and sporadic, and depend on an unusual combination of circumstances. In the case of Suæda it is highly improbable that the plants are materially supplemented by this mode of introduction.

APPENDIX VII

List of Authorities in England and Wales having Powers and Duties in relation to Defence against the Sea

(1) A. Levens, Helsington, &c., Proprietors under Inclosure Award.
B. Milnthorpe and Heversham Marsh under Inclosure Award.
(2) Overton Commission of Sewers.
*(3) Thornton Marsh Inclosure Trust.
(4) Bispham Carleton and Thornton Drainage District.
*(5) Frodsham and Helsby Drainage District.
*(6) Wallasey Embankment Commission.
(7) Hawarden Embankment Trust.
*(8) Llanasa Embankment Trust.
*(9) Rhuddlan Marsh Embankment Trust.
*(10) Malldraeth and Corsddaugau Marsh Drainage Commission.
*(11) Dysynny Valley Drainage District.
*(12) Berwick Embankment Proprietors under Inclosure Award.
*(13) A. Monmouthshire Commission of Sewers, Wentllog Level.
B. Monmouthshire Commission of Sewers, Caldicot Level.
(14) Leadon Valley Commission of Sewers.
(15) Lay Drainage District.
*(16) Commission of Sewers for the Lower Level of Gloucester.
*(17) Somersetshire Commission of Sewers.
*(18) Somersetshire Drainage Commission (under Act of 1877).
*(19) Braunton Marsh Proprietors under Inclosure Award.
*(20) Isle of Wight Commission of Sewers.
*(21) Commission of Sewers for the Western Parts of Sussex.
*(22) Arundel Commission of Sewers.

* Authorities whose areas abut on the sea and estuarial waters thus.

(23) Commission of Sewers for the Bramber Level.
(24) Adur River Drainage Trust.
*(25) Lewes and Laughton Levels Commission of Sewers.
*(26) Newhaven Harbour and Ouse Lower Navigation Trust.
*(27) Commission of Sewers for Pevensey, Hastings, &c., Levels.
*(28) Newhaven and Seaford Sea Defence Commission.
*(29) Eastbourne Corporation as Authority under Eastbourne Improvements Acts, 1879 and 1885.
(30) Rother Level Drainage Commission.
*(31) East Guldeford Level Commission of Sewers.
*(32) A. Walland Marsh and Elderton's Innings Commission of Sewers.
B. Denge Marsh Commission of Sewers.
*(33) *New Romney Level Commission of Sewers.*
*(34) The Lords, Bailiffs, and Jurats of Romney Marsh Level.
*(35) East Kent Commission of Sewers.
*(36) *Whitstable U.D.C. as Authority under Special Act of 1902.*
*(37) Teynham, Tonge, and Luddenham Commission of Sewers.
*(38) Iwade and Milton Commission of Sewers.
*(39) Commission of Sewers for Gravesend Bridge to Sheerness and Penshurst.
*(40) Commission of Sewers for Lombard's Wall to Gravesend Bridge.
*(41) Commission of Sewers for the Havering and other Levels.
*(42) Commission of Sewers for the Rainham Bridge and other Levels.
*(43) Commission of Sewers for the Fobbing Levels.
*(44) Canvey Island Sea Embankment Board.
*(45) Foulness Island Commission of Sewers.†
*(46) Commission of Sewers for the Dengey Levels.
*(47) Clacton U.D.C. as Authority under Special Act of 1906.
*(48) Tendring Level Commission of Sewers.
*(49) Falkenham and Felixstowe Commission of Sewers.
*(50) The Ramshott Level Owners.
*(51) Hollesley, Alderton, and Bawdsey Level Owners.
*(52) A. Sudbourne and Orford Commission of Sewers.
B. Iken Commission of Sewers.

† Now under War Department.

*(53) Minsmere Level Drainage Commission.
(54) Oulton, Carlton Colville, and Barnby *Drainage District.*
(55) Blything, Mutford, Lothingland, and Wangford Commission of Sewers.
(56) Burgh St. Peter Drainage District.
(57) Haddiscoe, Thorpe, and Aldeby Drainage District.
(58) Langley, Chedgrave, &c., Marshes Drainage District.
(59) Norton Drainage Commission.
*(60) Burgh Castle Drainage District.
*(61) Commission of Sewers for the Eastern Hundreds of Norfolk.
(62) Runham Drainage Commission.
(63) Muckfleet Commission of Sewers.
(64) Burgh and Billockby Drainage Commission.
(65) Winterton and Somerton Commission of Sewers.
(66) Martham and Repps cum Bastwick Commission of Sewers.
(67) Hickling Drainage Commission.
*(68) Hempstead, Happisburgh, &c., *Drainage Commission.*
*(69) Cromer Protection Commission.
*(70) Salthouse and Kelling Proprietors under Inclosure Award.
*(71) Cley and Wiveton *Drainage* and *Embankment Commission.*
*(72) Holme Common Proprietors under Inclosure Award.
*(73) Norfolk Estuary *Company.*
*(74) Nene Outfall (Wingland District Drainage Commission).
(75) A. Ouse Banks 1st District Drainage Commission.
B. ,, 2nd ,, ,,
C. ,, 3rd ,, ,,
D. ,, 4th ,, ,,
E. ,, 5th ,, ,,
F. ,, 6th ,, ,,
(76) Marshland, Smeeth, and Fen Drainage Commission.
(77) Wormegay-Polver Drainage Commission.
*(78) Nar Valley Drainage Board.
(79) Outwell, Stow Bardolph, Wimbotsham, and Downham Drainage Commission.
*(80) Ouse Outfall Conservancy Board.
(81) Ladus Fen Drainage Commission.

(82) Waldersey Drainage Commission.
(83) Wisbech Commission of Sewers.
(84) Wisbech North Side Drainage Commission.
(85) Leverington, &c., Drainage Commission.
(86) Tid and Newton Drainage Commission.
*(87) Nene Outfall (General) Drainage Commission.
*(88) Welland River Outfall Trust.
*(89) South Holland Embankment Trust.
*(90) Moulton Salt Marsh Drainage Trust.
*(91) Kirton Marsh Proprietors under Inclosure Award.
(92) A. Lincolnshire, &c., Commission of Sewers, Brigg Court.
B. Lincolnshire, &c., Commission of Sewers, Grimsby Court.
*C. Lincolnshire, &c., Commission of Sewers, (*a*) Spilsby, (*b*) Alford, and (*c*) Louth Courts.
D. Lincolnshire, &c., Commission of Sewers, Boston Court.
*(93) Freiston and Butterwick Proprietors under Inclosure Award.
*(94) Leverton Sea Embankment Proprietors under Inclosure Award.
*(95) Friskney Sea Embankment Committee.
*(96) Grainthorpe and Marshchapel Proprietors under Inclosure Award.
*(97) Tetney Drainage and Embankment Commission.
*(98) Barton upon Humber Proprietors under Inclosure Award.
*(99) Ancholme Level Drainage and Navigation Commission.
(100) Reedness and Swinefleet Drainage Commission.
(101) Goole Fields Drainage District.
(102) Selby Dam Drainage Commission.
*(103) Hessle and Anlaby Drainage Trust.
*(104) Cottingham Drainage Trust.
*(105) Winestead Level Drainage Commission.
*(106) Ottringham Drainage Commission.
*(107) Keyingham Level Drainage Commission.
*(108) Commission of Sewers for the East Parts of the East Riding of the County of York.
*(109) Beverley and Barmston Drainage Commission.

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